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To the memory of Wayne A. Pryor

STRATIGRAPHY OF EL CHANATE GROUP (LATE CRETACEOUS) AND ITS IMPLICATIONS FOR THE TECTONIC EVOLUTION OF NORTHWESTERN SONORA, MEXICO

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ABSTRACT

The Late Cretaceous El Chanate Group is a clastic and volcanic sequence, ranging from 700 to more than 2,800 m in thickness, deposited in a continental basin. It disconformably overlies the Lower Cretaceous Bisbee Group and underlies the Late Cretaceous (71 Ma) Tarahumara Formation. On the basis of major upward-fining cycles and different conglomerate compositions, three stratigraphic units were identified in the Sierra El Chanate: the Pozo Duro (oldest), Anita, and Escalante (youngest) formations. El Chanate Group and its three formations are proposed herein as formal stratigraphic units.

The Pozo Duro Formation varies in thickness from 152 to 665 m. Its lower part is composed of cream-colored quartz-arenite pebble conglomerates intercalated in red mudstone, deposited by meandering streams. The Anita Formation, which varies in thickness from 0 to 1,272 m, is divided into three members. The lower member consists of andesitic lava flows, breccias and agglomerates. The middle member consists of fluvial upward-fining cycles in which the conglomerates are composed mainly of andesitic pebbles and cobbles. The upper member consists of shale, sandstone and minor dark gray, thin-bedded fossiliferous limestone. Deposition took place in meandering rivers and a lake near volcanic centers. The Escalante Formation, 249- to 718-m-thick, is divided into two members. The lower member consists mainly of thick conglomerate wedges in which the clasts are mostly rhyolitic and andesitic. This unit was deposited first in alluvial-fan or braided-river environments that changed with time into meandering streams. The upper member consists of sandstone and shale couplets with some intercalations of rhyolite tuffs. Deposition probably took place in a lacustrine delta.

The El Chanate basin was probably a relatively small foreland basin elongate in a northwest-southeast direction. During deposition of El Chanate Group, the Caborca block was emplaced to the southwest of the basin along a northwest-trending thrust fault.

Key words: stratigraphy, tectonics, El Chanate Group, Late Cretaceous, Sonora, Mexico.

RESUMEN

El Grupo El Chanate, del Cretácico Superior, es una secuencia clástica y volcánica con un espesor que varía entre 700 y más de 2,800 m, depositada en una cuenca continental. Yace discordantemente sobre el Grupo Bisbee del Cretácico Inferior, y bajo la Formación Tarahumara, del Cretácico Superior (71 Ma). En la sierra El Chanate la secuencia se dividió en tres formaciones, con base en la presencia de ciclos de disminución de tamaño de grano hacia arriba y en las diferencias de composición de los clastos de conglomerado. Éstas son la Pozo Duro (más vieja), Anita y Escalante (más joven). Se propone aquí al Grupo El Chanate y sus tres formaciones como unidades formales.

La Formación Pozo Duro varía en espesor de 152 a 665 m, y en su base, se tiene conglomerados de clastos de cuarzo-arenitas de color crema. Estos sedimentos se acumularon en ríos meandrosos. La Formación Anita, que varía de 0 a 1,272 m de espesor, se divide a su vez en tres miembros. El miembro inferior consiste en derrames, brechas y aglomerados andesíticos. El miembro medio consiste en ciclos de disminución de tamaño de grano hacia arriba, en los cuales el conglomerado está formado de guijarros y guijas de composición andesítica. El miembro superior está formado por lutita, arenisca y caliza fosilífera gris oscuro escasa en capas delgadas. El depósito de estos miembros se llevó a cabo en las cercanías de centros volcánicos, en ríos meandrosos y, finalmente, en un lago. La Formación Escalante, de 249 a 718 m de espesor, se divide en dos miembros. El inferior consiste en gruesas cuñas conglomeráticas en las que los clastos son principalmente de rocas riolíticas y andesíticas. Este miembro se depositó como abanicos aluviales o ríos trenzados que, con el tiempo, cambiaron a ríos meandrosos. El miembro superior consiste en pares de arenisca y lutita con algunas intercalaciones de tobas riolíticas. El depósito de esta unidad se efectuó probablemente en un delta lacustre.

La cuenca El Chanate fue probablemente una cuenca de antepaís relativamente pequeña, orientada al noroeste-sureste. Al tiempo de su depósito, se emplazaba una placa por cabalgadura, probablemente hacia el sur de la cuenca. Esta placa es lo que ahora se conoce como bloque o terreno Caborca.

Palabras clave: estratigrafía, tectónica, Grupo El Chanate, Cretácico Tardío, Sonora, México.

INTRODUCTION

For many years most of the rocks in northwestern Sonora (Figure 1) were mapped incorrectly Jurassic or older (Anderson

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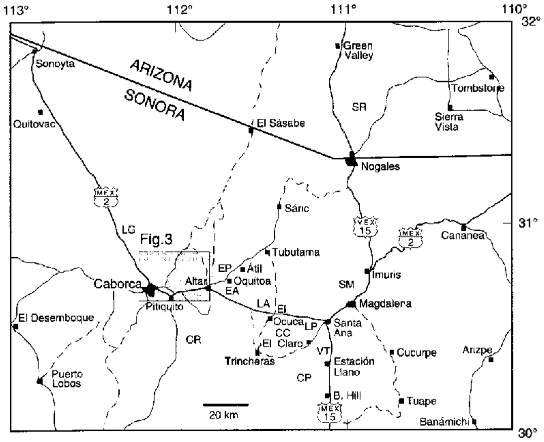

Figure 1. Map of northwestern Sonora showing the study area and other localities mentioned in text. CC, Cerros Cabeza Colgada; CP, Cerro Picacho; CR, Cerro Rajón; EA, Cerros El Amol; EP, Cerros El Puerto; LA, Cerros Los Alejos; LG, Sierra La Gloria; LP, Cerro La Pima; SM, Sierra de Magdalena; SR, Santa Rita Mountains; VT, Cerros La Vetatierra.

and Silver, 1979; Stewart *et al.*, 1986; Tosdal *et al.*, 1989). Now that many of these rocks have been dated as Cretaceous (Jacques-Ayala, 1983, 1993; Jacques-Ayala, Alencáster and Buitrón, 1990; Willard, 1988; Harrar, 1989; García y Barragán, 1992) a major revision of the geological evolution of northern Sonora is required. For example, many of the conglomerates exposed in the region are Late Cretaceous in age, the Bisbee basin is much wider (Jacques-Ayala, 1995) than previously considered by Bilodeau (1982) or Dickinson and collaborators (1986, 1989), its basement was a volcanic (mainly rhyolitic) terrane (Jacques-Ayala, 1993, 1995) and the Upper Jurassic appears to be conformably overlain by the Bisbee Group (Lawton and Olmstead, 1996). These new stratigraphic and sedimentologic findings provide evidence against the Nevadan orogeny in Sonora and the postulated trace of the Mojave-Sonora megashear (Silver and Anderson, 1974; Anderson and Silver, 1979).

The Cretaceous is widespread in northern Sonora and southern Arizona. The Late Jurassic-Early Cretaceous Bisbee Group is the reference stratigraphic unit in the region. It has been documented in many areas and is relatively well dated. The Upper Cretaceous is less well known than the Bisbee; the Fort Crittenden Formation and the Cabullona Group are the reference stratigraphic units for this epoch. The Cabullona Group was, until recently, the only Upper Cretaceous recognized in Sonora (Taliaferro, 1933; Hayes, 1970; Drewes, 1971). This basin was thought to be small and restricted to southeastern Arizona and northeastern Sonora. Recent discoveries suggest that it might be much larger, stretching as far south as Arivechi, in east-central (Pubellier, 1987; Grajales-Nishimura *et al.*, 1990) and central Sonora (Roldán-Quintana, 1994). Lucas and González-León (1990) collected an abundant vertebrate fauna which places the Cabullona Group in the Santonian-Maastrichtian. This is the same age as the Fort Crittenden Formation in southeastern Arizona (Figure 2).

Jacques-Ayala (1983) and Jacques-Ayala and Potter (1987) described for the first time El Chanate Group and Jacques-Ayala, García y Barragán and DeJong (1990a) assigned it to the Late Cretaceous. Other sequences of Late Cretaceous age in the Caborca area include the Tarahumara Formation (El Charro volcanic complex of Jacques-Ayala [1993]) which overlies El Chanate Group, and probably the Altar formation (García y Barragán, 1992; Jacques-Ayala, Alencáster and Buitrón, 1990); in the Cerro de Oro area, the La Palma formation (González-León and Jacques-Ayala, 1989); and in east-central Sonora the Tarachi unit (Pubellier, 1987) and the Tarahumara Formation (McDowell *et al.*, 1994) and an unnamed volcano-sedimentary sequence east of Moctezuma (Roldán-Quintana, 1994). Rodríguez-Castañeda (oral communication, 1994) and Grijalva-Noriega (oral communication, 1995) reported the presence of widespread Upper Cretaceous clastic sediments south and west of Cananea, in north-central Sonora (Figure 1).

El Batamote structural complex (Jacques-Ayala, 1993) extends along a NW-SE oriented, discontinuous belt from Estación Llano to Sonoyta. It consists of coarse to fine clastic sediments, volcanic and intrusive rocks, all of which have been locally deformed and metamorphosed to green schist and amphibolite(?) facies. Metamorphism of the Altar Schist (part of the El Batamote structural complex) has been dated using K/Ar by Damon and collaborators (1962) and Hayama and collaborators (1984) as 54 to 56 Ma. Some of the lithologic types that make the El Batamote structural complex are similar to the Upper Cretaceous. In the author's opinion, this means that deformation and metamorphism is latest Cretaceous to very early Tertiary, even though some workers have assigned a Late Jurassic age to it (Corona, 1979, 1980; Connors *et al.*, 1989; Caudillo-Sosa and Oviedo-Lucero, 1990; Caudillo-Sosa *et al.*, 1996).

AGE AND CORRELATION

Jacques-Ayala and Potter (1987) and Jacques-Ayala, Alencáster and Buitrón (1990) assigned an Albian age to the upper member of the Anita Formation, based on the presence of poorly preserved fossils: the pelecypod *Crassatella* (*Pachythaerus*) sp. Conrad and the gastropods *Rissoa dupiniana* d'Orbigny and *Tellina bogotina* d'Orbigny; however, this age appears to be inconsistent with the regional stratigraphic framework. In this work, El Chanate Group is assigned to the Late Cretaceous on the basis of its stratigraphic position and regional correlation. As of now, this age cannot be constrained further; El Chanate is younger than Albian because it overlies the Cintura Formation (which can be as young as late Albian) and includes clasts derived from it, and is older than Maastrichtian, because the age of the Tarahumara Formation in the Sierra El Chanate has been determined isotopically as 71 Ma by means of Ar^{40}/Ar^{39} (Jacques-Ayala, García y Barragán *et al.*, 1993). The

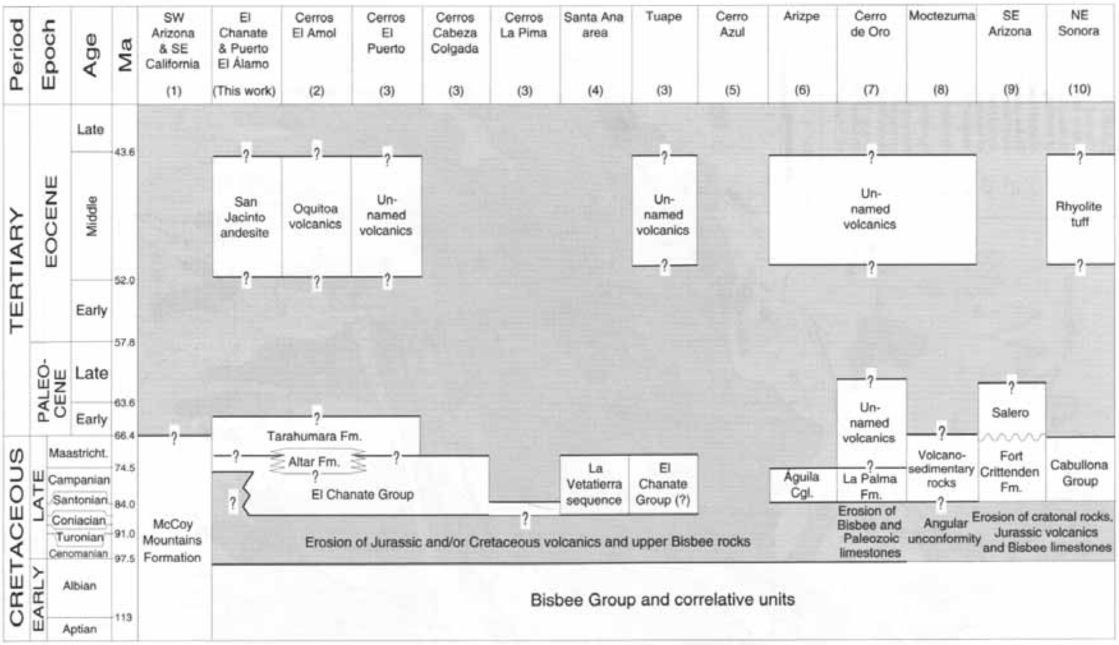

Figure 2. Correlation table of Jurassic-Eocene stratigraphic units of northern Sonora, southern Arizona and southeasternmost California. Sources of information: (1) Stone and others (1987); (2) García y Barragán (1992); (3) Jacques-Ayala (1993); (4) Jacques-Ayala (1992); (5) McKee (1991); (6) González-León (1978); (7) González-León and Jacques-Ayala (1988); (8) Roldán-Quintana (1994); (9) Dickinson and others (1989).

age of El Chanate Group is most probably Campanian to Maastrichtian, which is the same age of the Fort Crittenden Formation in southeastern Arizona and the Cabullona Group (Lucas and González-León, 1993) in northeastern Sonora.

Other units that are probably correlative to El Chanate Group are the Chino Group and probably part of El Rajón Group (Longoria and Pérez-V., 1979). A conglomeratic sequence overlying the Cintura Formation east of Tuape (Jacques-Ayala, 1993) could also be correlative to El Chanate. The Cocóspera conglomerate was assigned to the Late Jurassic by Nourse (1989, 1996), but recently Grijalva-Noriega (oral communication, 1995) collected clasts derived from the Mural Limestone, requiring that the conglomerate be post middle Albian. The Cabullona Group occurs in northeastern Sonora (Taliaferro, 1933; González-León, 1994; González-León and Lawton, 1996; Lucas *et al.*, 1996) and the correlative the Fort Crittenden Formation (Dickinson *et al.*, 1989) is present in southern Arizona. Extensive volcanic and volcano-sedimentary units correlative to the Cabullona Group have also been reported in east-central Sonora (Pubellier, 1987; Grajales-Nishimura *et al.*, 1990) (Figure 2).

STRATIGRAPHY

The Sierra El Chanate is the type locality for El Chanate Group (Figures 3 and 4). This group was first described by Jacques-Ayala (1983) as a formational unit divided into three members. Jacques-Ayala and Potter (1987) considered it a formation, but divided the sequence on the northern side of the range into seven members, and that on the southern side into

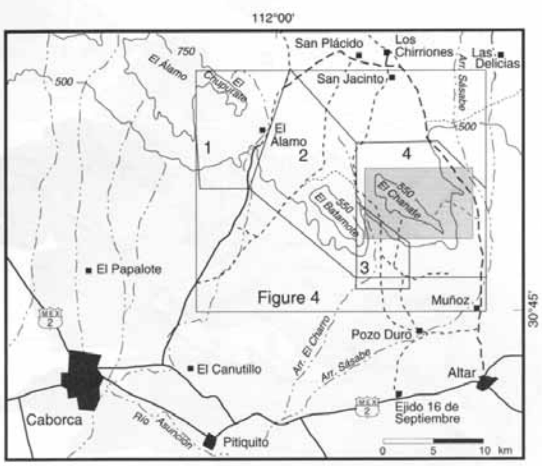

Figure 3. Location of the Sierras El Chanate, El Batamote and Puerto El Álamo. Large inset indicates location of Figure 4. Shaded inset indicates location of Figure 5. Sources of information for geologic map (Figure 4) are: (1) Willard, 1988; (2) Harrar, 1989; (3) McComb, 1987; (4) Jacques-Ayala, 1993.

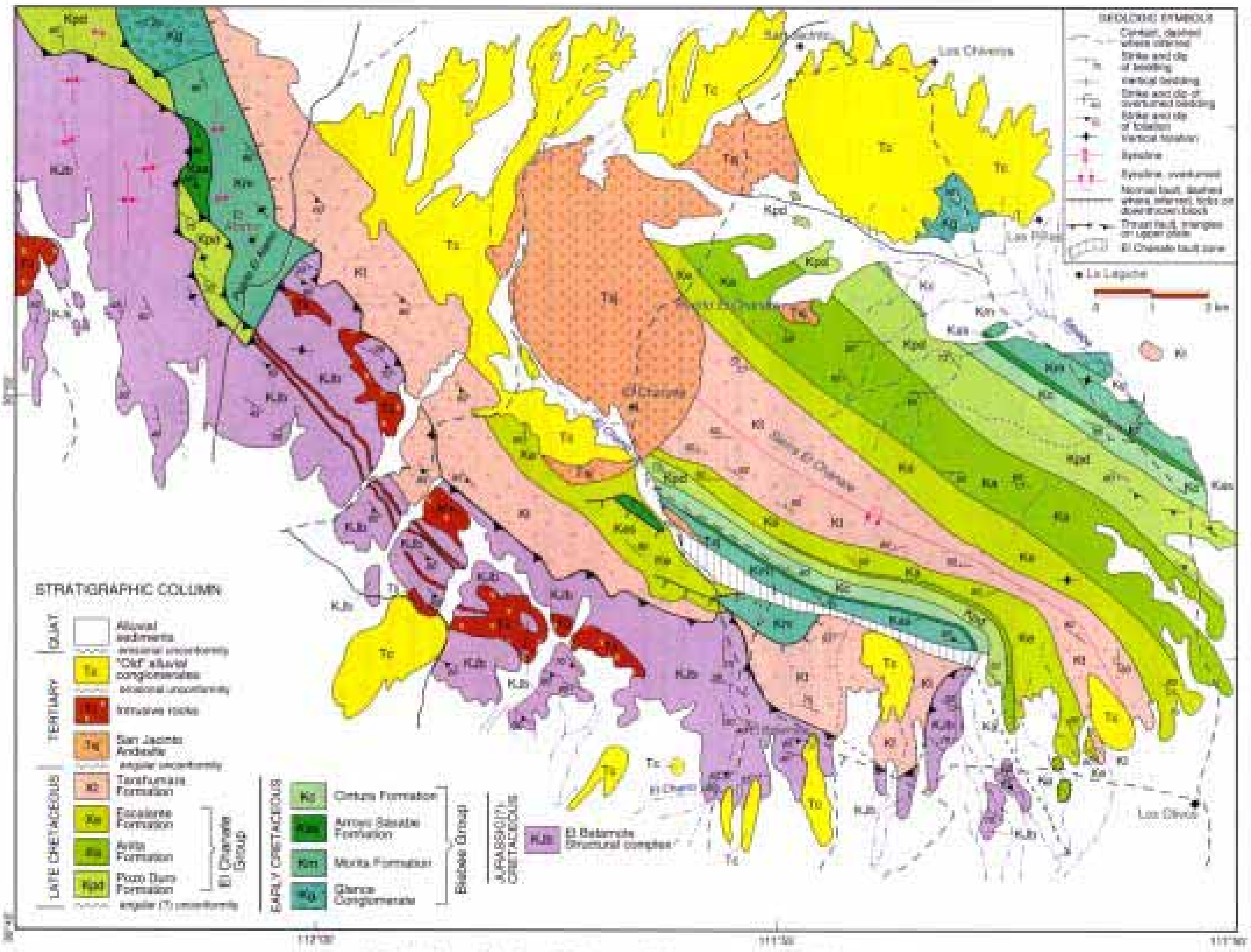

Figure 4. Geological map of the Sierras El Chanate and El Batamote and the Puerto El Álamo, NW Sonora.

three members. Jacques-Ayala, García y Barragán and DeJong (1990a) raised it to group status, and divided the group into three different formations. This new division was based on the composition of pebbles in the conglomerates as well as on textural variations; each change in pebble composition represents the base of an upward-fining cycle. In this work, the section on the south and north sides of the range is divided into the same three formations: the Pozo Duro (oldest), the Anita, and the Escalante (youngest). The sequence on the northern side is more than 2,800-m thick, and is complete. The sequence on the southern side is less than 750 m, and is also complete for it includes, even though drastically reduced in thickness, all three constituent formations (Figure 4). As no evidence of excising of part of the sequence has been observed and the bounding stratigraphic units match from one side to the other, the difference in thickness is interpreted to be of sedimentary and not of structural origin. Monreal and collaborators (1994) suggested that the group status of El Chanate be changed to formation because "the internal stratigraphy, although quite thick, is coherent...". Coherence is, however, only apparent; the sequence consists of clastic sediments and volcanic rocks, but three main units can be very well identified on the basis of composition. Furthermore, each formation can be divided into several members. Therefore, the group status is appropriate, and is retained here.

Four stratigraphic sections were measured: one on the northern side of the mountain and three on the southern side (Figure 5). The reader is referred to the Appendix for a detailed description of the sections.

El Chanate Group was deposited disconformably upon the Bisbee Group, even though the presence of a locally angular unconformity is not ruled out. The shift from coastal and deltaic (Cintura Formation) to meandering fluvial environments (Pozo Duro Formation), emphasized by the presence of quartz pebble conglomerates, suggests that the time lapsed between them is apparently not significant, or that no major tectonic event occurred. Locally there appears to be an angular unconformity of minor discordance. On aerial photographs some linear features suggest an angular unconformity in the southwestern part of the area, but structural complications obscure this relationship in the field. In Puerto El Álamo the relationship is similar to that in the El Chanate area. Overall, the structural position of both units is similar and any angular unconformity present is very gentle.

The Anita Formation rests paraconformably upon the Pozo Duro Formation. The contact was not observed in the field, but the two formations are concordant. There is probably a hiatus between the two, suggested by the sudden appearance of volcanic activity in the lower Anita Formation. A similar

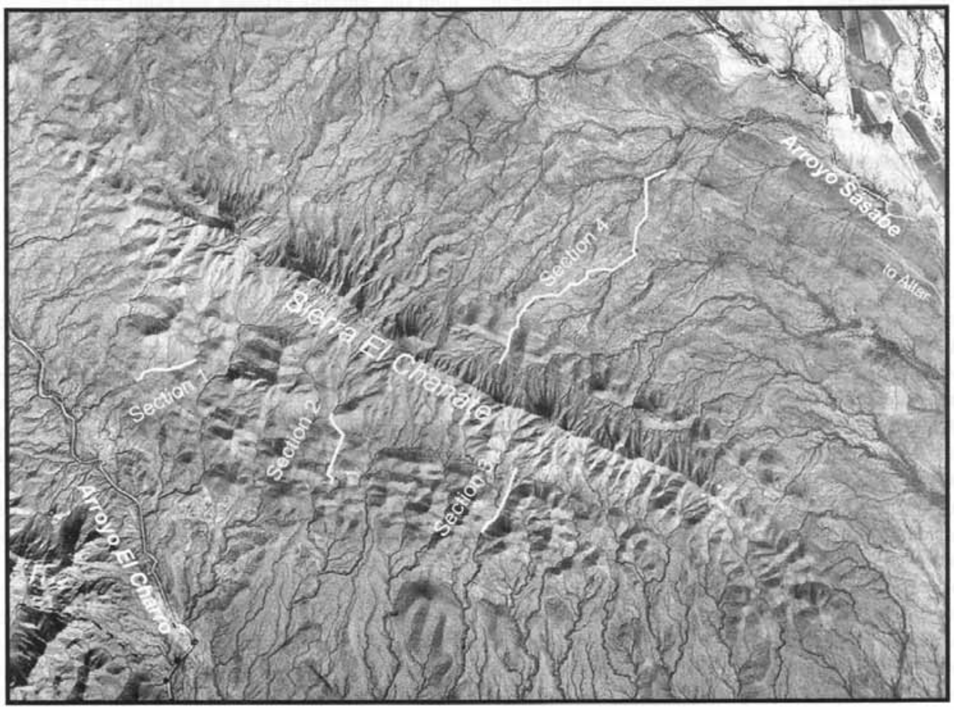

Figure 5. Aerial photograph showing the location of the measured stratigraphic cross sections. Approximate scale is 1:70,000.

relationship exists between the Anita and the overlying Escalante Formation.

The upper contact with the Tarahumara Formation is apparently disconformable. In the southern side of the mountain, the tuffs and breccias of the Tarahumara have the same structural attitudes as the uppermost El Chanate Group. In other places, the upper member of the Escalante Formation displays folds, suggesting an angular relationship. In the author's opinion, these folds form because of incompetence of the sandstone-shale section between the massive conglomerates below and the massive volcanics above. On the southwestern part of the area, the Tarahumara changes its trend, so El Chanate appears to abut against it in angular unconformity. A similar situation is observed on the northwestern side of the mountain, but the contact might be faulted. The time represented by the upper contact is interpreted to be minimal because the thin rhyolitic tuffs intercalated in the upper part of the Escalante Formation are similar to thick rhyolitic tuffs in the basal Tarahumara Formation.

POZO DURO FORMATION

The Pozo Duro Formation is named after the Pozo Duro Ranch, which encompasses most of the area of the Sierra El Chanate. This unit crops out also in Cerros El Puerto, in western Cerros Cabeza Colgada, Cerros Los Alejos and in Cerros El Amol (García y Barragán, 1992). Small exposures of the base of the unit have been identified in Cerro La Pima. It is probably present in the Puerto El Álamo, but has not been clearly identified.

The Pozo Duro Formation in the Sierra El Chanate includes members NEC-1 and the lower part of NEC-2 of Jacques-Ayala and Potter (1987). This formation is exposed on the northern limb of the Sierra El Chanate, where it is 665-m thick (Figure 6) and on the southern limb as well, where it attains, from west to east, 152, 229 and 208 m in thickness. The section on the northern limb (Section 4) is the type section for the Pozo Duro Formation. The other sections are reference sections that illustrate thickness variations. The unit underlies nearly flat areas, except at the base, where it forms elongate, strike-parallel hills formed because the conglomerates are resistant to erosion. Arroyos generally cut across the unit where conglomerate is absent or very thin. In aerial photographs and satellite images the base of the unit is clearly marked by the white streaks of the conglomeratic lenses.

The Pozo Duro Formation is a succession of mudstone, shale, sandstone and conglomerate (Figure 6). Most of the unit consists of red to purplish red and brown, massively bedded, mudstone and shale. The sandstone is red to purplish red and cream colored and medium to thick bedded. Overall, grain size ranges from fine to coarse. Coarse-grained sandstone predominates near the base of the formation, whereas fine-grained ones predominate toward the top. Beds display plane-parallel and cross lamination. The gray to purplish-red sandstones are mainly lithic arenites, whereas the cream-colored ones are quartz-rich, coarser grained and conglomeratic. The conglomerates are cream colored, lens shaped, and generally less than 2-m thick. Pebbles and granules are rounded to subrounded, and consist mainly of quartz sandstone and subordinated amounts of volcanic rocks and vein quartz. Toward the top of the section, there are some brown conglomerate lenses which include quartz-porphyry and andesite.

Conglomerate abundance and grain size vary on opposite sides of Sierra El Chanate. In the lower 200 m of the Pozo Duro, the conglomerates are more abundant than elsewhere. The amount of sandstone increases upward acquiring gray to red and green colors. Near the top, the unit consists mostly of shale and mudstone. In the southern Sierra El Chanate, conglomerates are thicker, and the clasts are larger than those on the northern side of the range, but also fines upward. Near the top, in the central portion of the sierra several lenses of volcanic-pebble conglomerate occur. Sparse fragments of black silicified wood occur in different places within the unit. In one place a tree trunk about 50 cm in diameter was found.

The Pozo Duro Formation is also exposed in the Cerros El Puerto (Figure 1), where it is at least 800-m thick (Jacques-Ayala, 1993). It forms, generally, upward-fining cycles from pebble conglomerate to shale and mudstone. The fine-grained rocks are red to purplish red and purple and also green. They are medium to thick bedded, and locally display internal bedding and lamination. Sandstone is greenish gray to buff, and ranges from fine and silty to coarse and pebbly. It is medium to thick-bedded. The composition of the sandstone varies from quartz-rich to lithic-rich. The conglomerate is cream colored, forms lenses not thicker than about 2 m, and is matrix supported. The pebbles are rounded and consist mainly of quartz sandstone and minor volcanic fragments. The contact with the Bisbee Group is a fault; the upper contact with the Tarahumara Formation of latest Cretaceous age is also a fault.

In the Cerros Cabeza Colgada (Figure 1) the Pozo Duro Formation forms the main topographic features in the area. It is found west of the road from El Ocuca to Trincheras, extending to the northwest into the Cerros Los Alejos (Rancho San Pascual) area, where it is well exposed. The Pozo Duro Formation consists of red to purplish red mudstone and siltstone, and gray to purplish gray sandstone. At the base there are lenses of quartz-rich sandstone and quartz-arenite pebble and conglomerate. In the western part of the area the conglomerate lenses are thin and matrix-supported and the pebbles are small. In the surroundings of the Rancho San Pascual, to the north, the Pozo Duro Formation has conglomerate lenses that are about 3- to 4-m thick, and consist of rounded, quartz-sandstone pebbles and cobbles.

In the area of Cerro La Pima (Figure 1), the Pozo Duro Formation is sparingly exposed in the northern part, near Rancho El Represito. The exposure is a few meters thick and consists of thin veneers of quartz-sandstone pebble conglomerates intercalated in red to reddish purple mudstone. These red mudstones are similar to those in the underlying Cintura Formation.

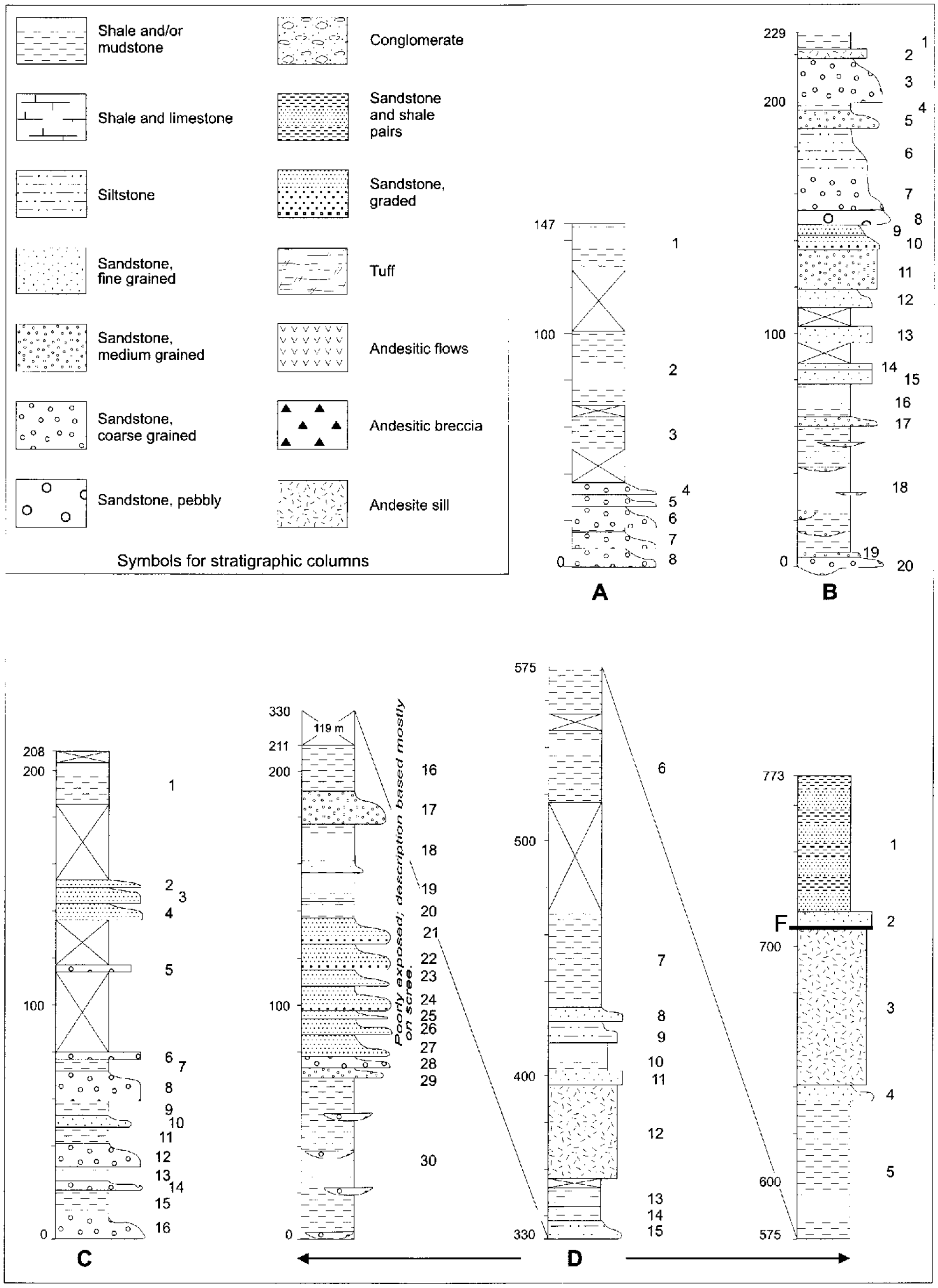

Figure 6. Stratigraphic columns of the Pozo Duro Formation: Section 1 (A), Section 2 (B) and Section 3 (C), on the southern Sierra El Chanate; Section 4 (D) on the northern Sierra El Chanate. Lithologic symbols for stratigraphic columns in figures 6 through 10. Ticks on the left side of the columns indicate 20 m intervals unless otherwise indicated. Numbers to the right of the column indicate number of unit in the description of the section in Appendix.

ANITA FORMATION

The Anita Formation is the intermediate unit of El Chanate Group. It is named after the Rancho Anita, located on the eastern end of the Sierra El Chanate, across the Arroyo Sásabe and south of the Rancho Aurora. The Anita Formation includes the upper part of member NEC-2 and members NEC-3, NEC-4 and NEC-5 of the El Chanate Formation of Jacques-Ayala and Potter (1987). The Anita Formation has been identified only in the Sierra El Chanate. A small exposure of andesite-pebble conglomerate that occurs in Cerro Picacho, east of Trincheras, beneath Proterozoic dolomite, is probably equivalent to the Anita.

The Anita Formation is exposed on the northern side of the Sierra El Chanate where it is more than 1,220-m thick and in the southern side where it is at most 140-m thick and wedges out completely toward the northwest (Figures 4 and 6). The section on the northern side (Section 4) is the type section for the formation.

The Anita Formation is divided into three distinctive members: lower, middle and upper. On the northern side of the range, all three members occur, whereas on the southern side only the lower and middle members are locally present.

Lower member. The lower member is an andesite consisting of flows and volcanic breccias with sparse sedimentary conglomerate intercalations (Figure 7). In the southeastern part of the northern exposures it is about 300-m thick, and thins to about 50 m toward the west. Flows are predominant toward the east, but are poorly exposed. They consist of light olive-gray, massive, aphanitic to porphyritic, highly altered andesite with plagioclase and amphibole phenocrysts. The volcanic breccias are made of angular to subrounded fragments embedded in a volcanic matrix of the same composition. Locally, the matrix is sandy with a strong hematitic coloration. The conglomerate is composed mainly of andesite fragments in a sandy to tuffaceous matrix. The contact with the middle member is covered, but appears to be transitional, for the angular breccias grade upward into rounded conglomerates and the tuffaceous matrix becomes sandier upsection. In the southeastern part of the southern exposures, a section at least 50-m thick consists of volcanic conglomerate, thick tuffs and volcanic breccia overlain by strata of the middle member. The stratification is massive and is indicated by size and roundness differences of clast layers. Toward the northwest the lower member in the southern limb is 110-m thick, consisting of andesite flows with a few thin volcanic breccias near the top (Figure 7). Farther northwest, it wedges out and disappears. Locally, volcanic breccias less than 1-m thick can be observed. The contact with the middle member is conformable and abrupt.

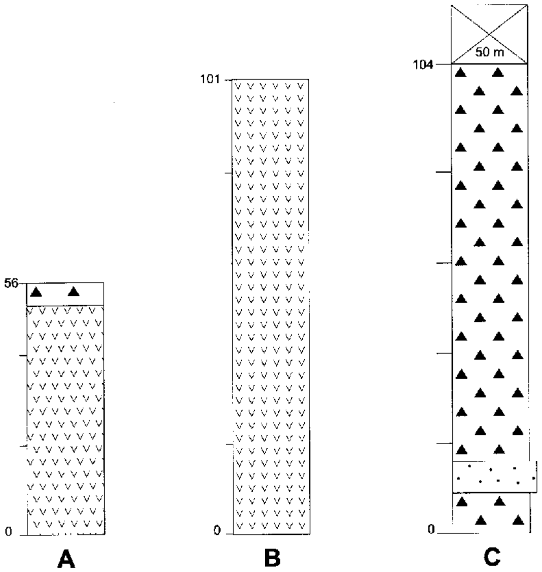

Figure 7. Stratigraphic columns of the lower member of the Anita Formation in the Sierra El Chanate: Section 2 (A) and Section 3 (B), southern limb; Section 4 (C) on the northern side.

Middle member. The middle member of the Anita Formation on the northern side of the mountain is 807-m thick and consists of shale, mudstone, sandstone and conglomerate forming upward-fining cycles. In contrast with the Pozo Duro Formation, the conglomerates of the Anita consist mainly of andesite with subordinate amounts of rhyolite and local intercalations of quartz-arenite pebble conglomerates. Throughout the section, the proportions of the components vary. Average clast size is much larger on the northern side than on the southern side of the mountain. For convenience of description, the member is divided into five units.

Unit 1. The basal 132 m consist of conglomerate with sandstone intercalations (Figure 8). The conglomerate is mottled to red and gray with purplish hues, lenticular to thick-bedded and massive and clast supported. The matrix is sandy to silty. The clasts are rounded to subangular, poorly sorted, and are made mostly of andesite. The sandstone is red, medium bedded, and coarse to gravelly. Sandstone becomes more abundant, finer grained and parallel laminated toward the top, even though locally some upward coarsening facies occur. The contact with the overlying unit is sharp.

Unit 2 is 65-m thick, and consists of shale with intercalations of sandstone and conglomerate. The shale is red to gray to dark gray, massive, and contains some calcareous nodules. It is foliated, strongly fractured and poorly exposed. Sandstone is red, medium to thick bedded, and medium to fine grained. The upper contact of the sandstone is gradational with the shale. Locally there are lenses and beds of red, coarse to gravelly sandstone and conglomerate. The conglomerate is clast-supported, poorly sorted, and consists mostly of andesitic pebbles.

Unit 3 consists of 130 m of conglomerate, sandstone and shale in upward-fining cycles. The conglomerate is massive, clast-supported, poorly sorted, with cobbles as large as 30 cm.

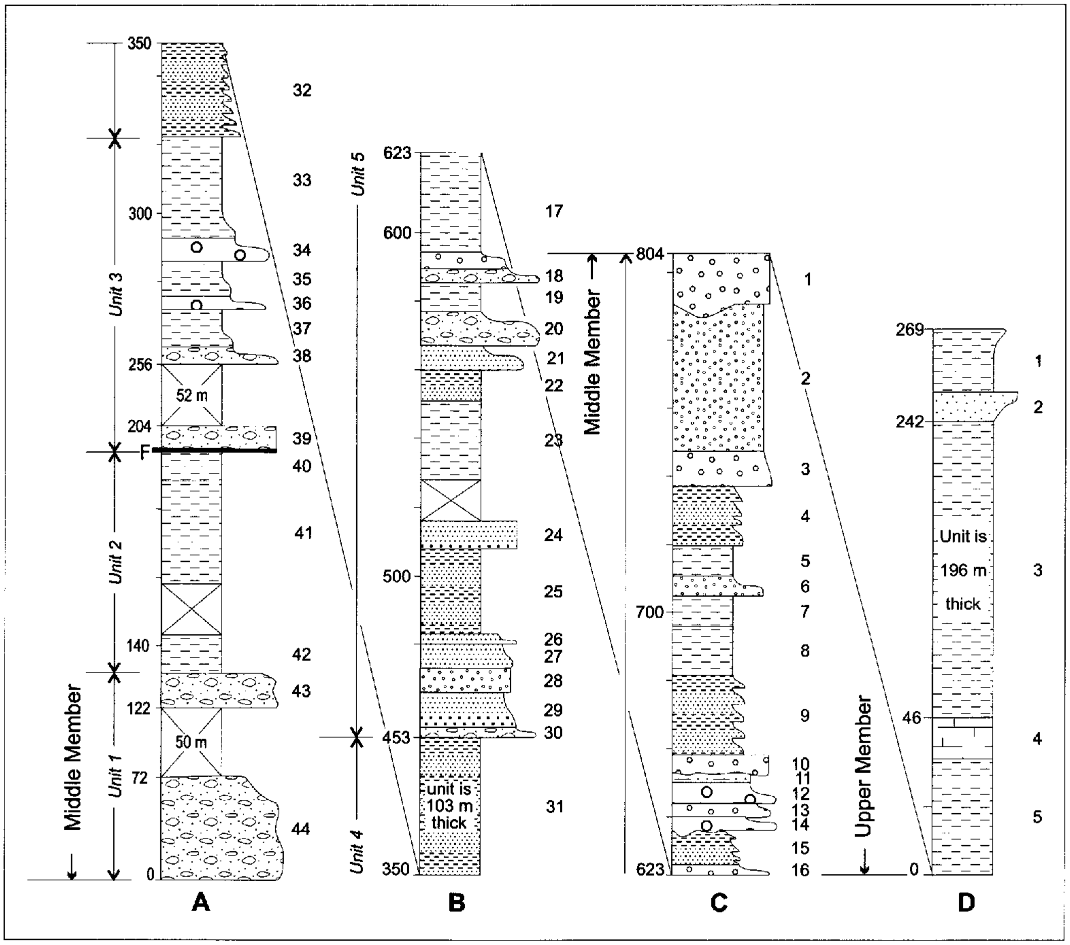

Figure 8. Stratigraphic column of the middle and upper members of the Anita Formation in the northern Sierra El Chanate.

The composition of the clasts is mainly andesite, but it includes also quartzose and lithic sandstone. The sandstone is red, medium- to coarse-grained and pebbly, medium- to thick-bedded. Plane-parallel and cross lamination are common, as well as bioturbation structures. The shale is red, massive to thickly laminated, with disseminated calcareous nodules and intercalations of red, fine-grained sandstone and silt. The contact with the overlying unit is gradational.

Unit 4 is 126 m thick, and consists mainly of shale with minor intercalations of sandstone and conglomerate. It is similar to unit 2, but the coarser fraction is more abundant.

Unit 5 (formerly Member NEC-4 of Jacques-Ayala and Potter [1987]) consists of 351 m of upward-fining cycles made of conglomerate, sandstone and shale. The conglomerate is red to gray and mottled, massive to medium-bedded and lenticular. It is grain supported, poorly sorted, with clasts in the cobble range. The composition of the clasts is mainly andesite, plus quartz sandstone, chert, and others. Locally, the conglomerate is composed almost entirely of quartz-sandstone pebbles, in which case it is cream-colored. The sandstone is medium- to thick-laminated, pebbly to coarse- and medium-grained, and displays plane-parallel and cross-lamination. The upper parts of the cycles are composed of red, massively bedded shale with thin intercalations of red siltstone to fine-grained sandstone with small calcareous nodules. The shale is locally foliated.

Upper member. The upper member of the Anita Formation is 264 m thick, and consists of shale with some interbeds of sandstone and minor limestone (Figure 8). The shale is red to green to purplish brown, but weathers to tan and ocher where fractured. It is massive and foliated. It contains calcareous nodules that are irregularly distributed, and become larger and more abundant up-section. About 30 m above the base is a 12 m-thick zone of dark gray (weathering to olive green and ocher) shale with thin intercalations of dark gray to black limestone and calcareous shale. The limestone is micritic and shaly, and contains poorly preserved pelecypods and gastropods. The sandstone is buff to purplish gray and ocher green, thin- to medium-bedded, fine- to medium-grained. The upper part of the member is a coarsening upward sequence.

ESCALANTE FORMATION

The Escalante Formation is named after the Rancho Escalante, located on the eastern end of the Sierra El Chanate, across the Arroyo Sásabe. This formation is 718 m thick on the northern limb of the Sierra El Chanate, whereas on the southern limb it varies from 349 to 491 m. The section on the northern side (Section 4) is the type section for the Escalante Formation. The formation is divided into two members. The lower member includes thick, ridge-forming conglomerate wedges. These are more abundant on the northern side. The upper member is a succession of buff to greenish buff sandstone and shale couplets. This member is a valley-forming unit, as can be observed along both sides of the backbone of the Sierra El Chanate, where it forms depressions between the more resistant lower member and the Tarahumara Formation. The Escalante is well exposed on both sides of the El Chanate, although on the southern side it is greatly reduced in thickness. The Escalante Formation contains fragments of black, silicified fossil wood, most found as float. These are small in size, and only rarely the whole diameter of a trunk was found. Some fragments appear to be carbonized.

Lower member. The lower member of the Escalante Formation is exposed on both sides of the Sierra El Chanate. On the northern side it is 510 m thick (Figure 9), and consists of thick conglomerate wedges with intercalated sandstone and mudstone forming upward-fining cycles. The conglomerate is gray to purplish gray and red to buff to reddish buff, massive to thick, clast-supported, with a sandy matrix. Thickness of the conglomerate varies from about 5 up to 30 m. Clasts include quartz porphyry, flow-banded rhyolite, and subordinate amounts of andesite, quartz sandstone and lithic sandstone. Locally the felsic fragments make the bulk of the coarse fraction.

Sandstone is gray to purplish gray and green, medium to thick bedded, coarse and pebbly to medium-grained. It displays graded, plane parallel and cross lamination. Where the underlying lithology is conglomerate, the contact is typically gradational; where it is shale, the contact is scoured. Some sandstone beds have a conglomeratic base.

Mudstone and shale intervals are common, forming the upper parts of upward-fining cycles. Their bases are transitional with sandstone, and their upper contacts are sharp and locally scoured. They are green to red and purple, medium- to thick-bedded. Locally present are calcareous nodules, generally not more than 10 cm in diameter, concentrated along bedding planes or disseminated. Intercalations of thin to medium beds of siltstone and fine-grained sandstone are common, and are usually of the same color as the shale. On the northeastern side of the range, the mudstone is red, massive and very resistant to erosion. It resembles the mudstone in the Morita and Cintura Formations. The fine-grained portions of the member display a pervasive foliation which can locally be seen in the coarser grained beds.

On the southern side of the Sierra El Chanate, the lower member attains thicknesses of 283, 245 and 145 m in three different measured sections (Figure 9, columns A, B and C), decreasing from southeast to northwest. The sequence is similar to that on the north, but with a thickness reduced to about one half. The main criteria used to correlate the sections on both sides of the range are their identical stratigraphic position relative to the upper member and to the Tarahumara Formation at the top, to the Anita Formation below, as well as pebble composition.

The sequence described by Willard (1988) as El Chanate Formation in the Puerto El Álamo is here assigned to the Escalante Formation. Willard (1988, p. 188) measured a section 630 m thick. Of these, the basal 60 m are included in the Cintura Formation, and the upper 570 m to the Escalante (Jacques-Ayala, 1993). Assignment to the Escalante Formation is based on the clast composition of the conglomerates: mostly rhyolite with subordinate amounts of quartz-arenite. The quartz-arenite clasts appear to be absent in the Glance Conglomerate of the region, thus suggesting a different identification. The lower member of the Escalante Formation is 220 m thick and consists of conglomerate and sandstone forming upward-fining cycles. The conglomerates are brown and gray, massively bedded, and consist of pebbles and cobbles made of quartz porphyry, and minor quartzite. Interbedded sandstone is found throughout the member. It is grayish red to dark reddish brown, poorly to moderately sorted, and mainly of volcanic origin. The Escalante Formation in Puerto El Álamo constitutes an upward-fining sequence.

Upper member. The upper member of the Escalante Formation is a valley-forming unit. It consists of sandstone and shale couplets. As it erodes easily, it forms gentle slopes. The section measured on the northern slope of the Sierra El Chanate is 207 m thick. On the southern side, three other sections are 189, 145 and 188 m thick, from west to east. (Figure 10).

The upper member consists of brownish and reddish green to purple and reddish purple sandstone, medium- to coarse-grained and locally pebbly. Beds vary in thickness from a few centimeters to almost a meter, typically on the order of 0.5 m. Some beds have a conglomeratic base. On the northern side of the mountain, beds are thick low in the section, thinner upsection, and near the contact with the Tarahumara Formation are coarse-grained. A similar variation is observed on the southern side of the range. The shale is brownish to olive green and purple and typically forms beds less than 0.5 m thick, although some beds are a few meters thick. It is generally fissile, and the thicker beds display pencil structure. Toward the upper part of the section there are thin, cream-colored rhyolitic tuffs, mostly less than 10 cm thick. They are similar to the thick, greenish

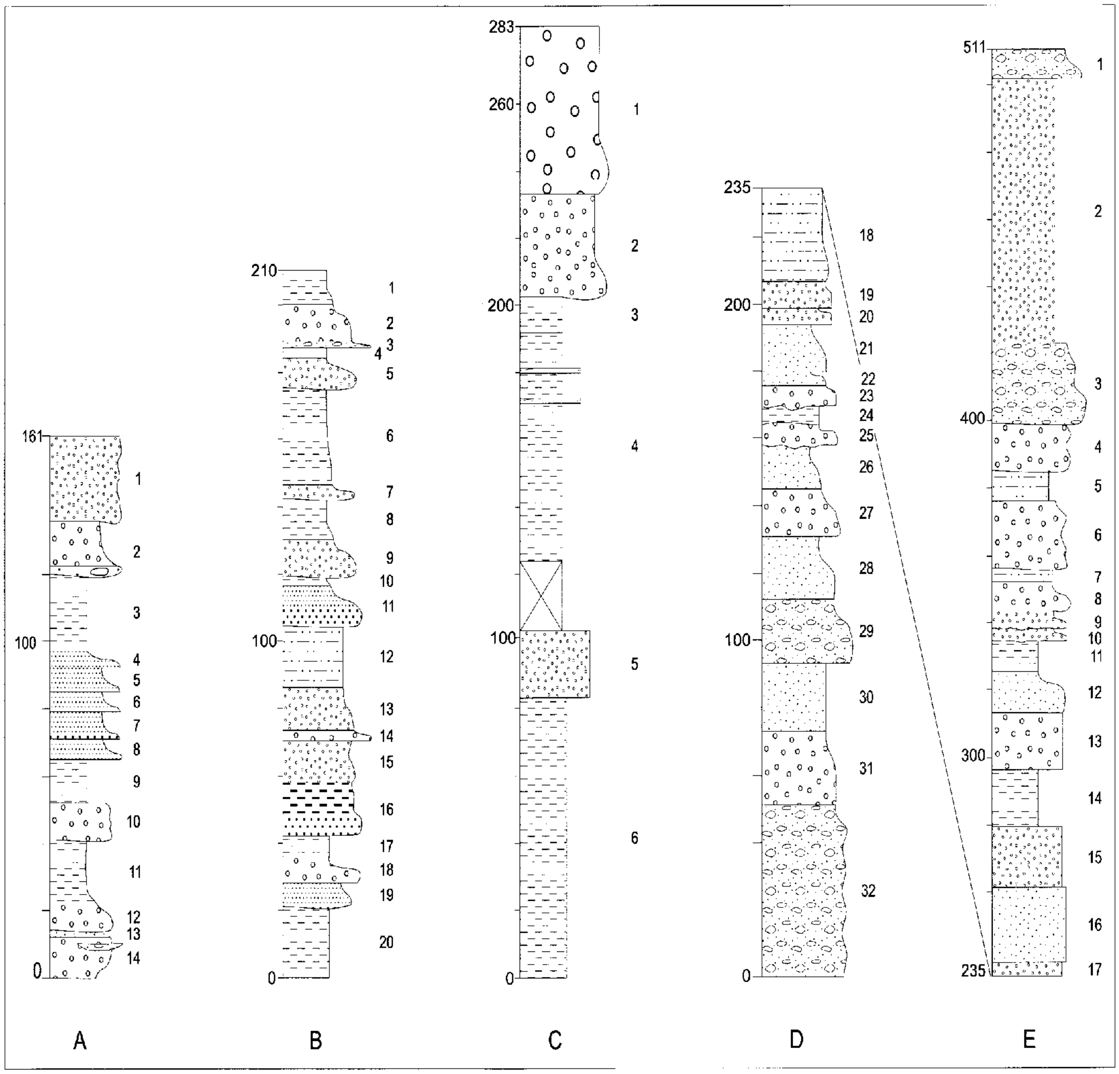

Figure 9. Stratigraphic column of the lower member of the Escalante Formation: Section 1 (A), Section 2 (B) and Section 3 (C) on the southern Sierra El Chanate; Section 4 (D and E) on the northern Sierra El Chanate.

gray tuff at the base of the Tarahumara Formation. On the eastern part of the southern exposures, light gray, thin stromatolitic limestone lenses occur.

OTHER LOCALITIES

In the valley between the Sierra El Chanate and Sierra El Batamote is exposed a conglomeratic sequence displaying variable amounts of deformation, from undeformed to strongly flattened, with well developed foliation and stretched pebbles. These rocks were included in El Batamote Formation by Jacques-Ayala (1983). Harrar (1989) placed them within El Chanate Group and Jacques-Ayala, Alencáster and Buitrón (1990) included them within El Batamote structural complex. While revising the geology of the northern slope of the Sierra El Batamote, the author identified the Tarahumara Formation and the upper member of the Escalante Formation. In stratigraphic contact beneath the upper member, are a series of conglomerate horizons that extend downslope into the Arroyo El Charro, between the Sierras El Batamote and El Chanate. Therefore, the variably deformed conglomerates are here assigned to the lower member of the Escalante Formation. Part of this sequence is

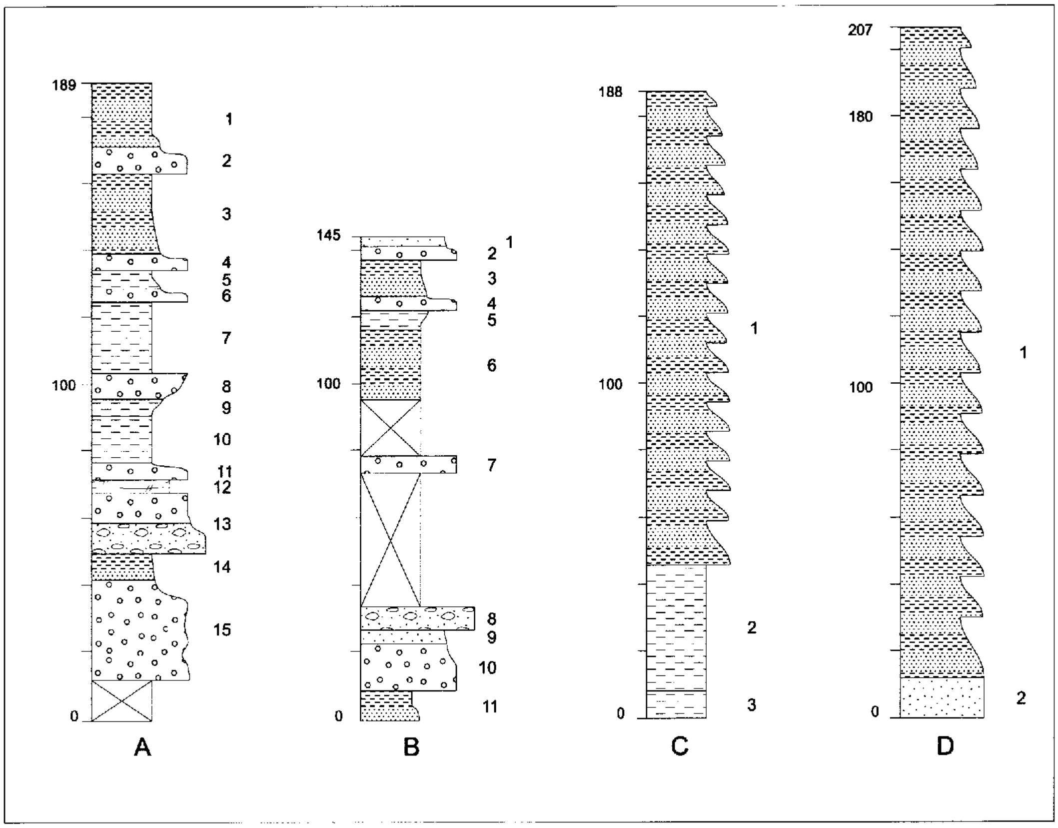

Figure 10. Stratigraphic column of the upper member of the Escalante Formation in the Sierra El Chanate: Section 1 (A), Section 2 (B), and Section 3 (C) on the southern side; Section 4 (D) on the northern side.

located along the El Chanate fault zone, which makes the conglomerates difficult to recognize; in addition to being stretched by deformation, they are hydrothermally altered and stained. These rocks extend northwestward to a point where they are covered by the San Jacinto andesite (Figure 4). Toward the southeast, they abut against andesitic breccias and conglomerates of unknown age. These breccias may be correlative with either the Anita or the Tarahumara formations.

In the Puerto El Álamo, the upper member of the Escalante Formation has a partial thickness of 350 m (Willard, 1988). The total thickness is unknown because the unit is cut at the top by a thrust fault. The upper member consists mainly of brown, greenish brown to gray and maroon sandstone and siltstone, locally with thin conglomerate lenses. This unit contains black silicified fossil wood. In the study area, fossil wood has been collected only from El Chanate and the Bisbee groups. The entire member displays a penetrative foliation, which increases upward to the contact with the El Batamote structural complex (El Alamo Formation of Willard [1988]). The boundary between both units is strongly foliated.

ALTAR FORMATION

The Altar Formation (Jacques-Ayala, Alencáster and Buitrón, 1990; García y Barragán, 1992) is exposed in the Cerros El Amol and probably in the Sierra El Batamote and Sierra La Gloria. Similar rocks have been observed to the northwest in Quitovac, near Sonoyta. Lithologies similar to those found in El Chanate Group have been described from Altar (García y Barragán, 1992) but, because of structural complexities, the stratigraphy has not been established. Two conglomerates, one with andesite pebbles and the other with cobbles and pebbles of quartz-porphyry are present in the Altar Formation. It also includes thick conglomerate wedges with clasts composed of quartz sandstone and volcanic rocks; those of quartz sandstone may be as large as 1 m. This unit is similar to parts of El Chanate Group, even though clast size in the Altar is much greater. The Altar also includes abundant fossil wood and stromatolitic limestone lenses, also reported in El Chanate. Worth mentioning is the fact that in central Sonora, the Upper Cretaceous includes stromatolitic limestone lenses, some with fossiliferous chert, intercalated in volcanic sequences. The age of the Altar Formation is therefore assumed to be Late Cretaceous. It may be in part correlative to the upper El Chanate Group, and in part to the Tarahumara Formation, as well. The reader is referred to García y Barragán (1992) for a description of the sequence.

One of the main characteristics of the Altar formation is its degree of deformation. Along highway 2, in the surroundings of Altar, this unit is strongly deformed and metamorphosed to greenschist facies (Hayama *et al.*, 1984). Metamorphism and deformation decrease northward, and apparently down the stratigraphic sequence, thus indicating the presence of an inverted metamorphic gradient. Metamorphism has been dated at 54–56 Ma (Damon *et al.*, 1962; Hayama *et al.*, 1984). This metamorphic sequence has a regional distribution forming a belt that extends from Estación Llano through Altar and into Sonoyta (see Figure 1 for localities). It continues northwest into southeastern California, where it is named the Orocopia Schist belt. The age cited above is assumed as the age of the Laramide orogenic phase, although Jacobson (1990) thinks of it as the age of uplift. In either case, deformation and metamorphism along this belt represent a regional feature most probably related to a thrusting event.

The Altar Formation was deposited, probably rapidly, near to its source area as alluvial fans. It appears to be geographically restricted, so it could have been shed into a small, rapidly subsiding basin. As the unit with the strongest deformation in the area, it is thought to have been deposited near to a thrust front and subsequently deformed by the advancing thrust plate. As of now, this hypothesis is the most likely.

PALEOGEOGRAPHY

Sedimentation in the Early Cretaceous Bisbee basin ceased at the end of the Albian. Marine sedimentation continued toward the east in the Chihuahua basin (Mar Mexicano of Araujo-Mendieta and Estavillo-González, 1987) in an area now largely covered by the volcanics of the Sierra Madre Occidental. In New Mexico marine sedimentation was continuous throughout the Cretaceous (Cumella, 1983; Mack, 1987; Mack *et al.*, 1988). Uplift in Sonora was apparently related to an orogenic phase evidenced by folding and thrusting in several areas.

In Late Cretaceous time, Sonora and Arizona underwent an episode of deformation that advanced into the region from the west or southwest (Dickinson, 1989). Eastern Sonora and southern Arizona were part of the fold and thrust belt in this orogenic system (Rangin, 1977, 1986; DeJong *et al.*, 1988; Pubellier and Rangin, 1988; Jacques-Ayala, García y Barragán and DeJong, 1990b; Drewes, 1992; Jacques-Ayala, DeJong and García y Barragán, 1993; Jacques-Ayala, 1993). The early Late Cretaceous orogenic phase (Calmus and Radelli, 1987) is thought to have induced the formation of relatively small continental basins, probably elongated in a NW-SE to N-S direction. One of these basins is the Cabullona basin (Taliaferro, 1933; Lucas and González-León, 1990; González-León, 1996) which connected with the Fort Crittenden basin to the north (Hayes, 1987), and stretched probably as far south as the Sahuaripa area (Pubellier, 1987). A separate basin is located southeast of Moctezuma, in central Sonora. This basin extended to the north into the Banámichi area, where stromatolitic limestones are intercalated with volcanic rocks (Bojórquez-Ochoa and Rosas-Haro, 1988; Ricalde-Moreno and Cevallos-Ferriz, 1993) and probably farther north into the Arizpe area (González-León, 1978). In the northwest, the El Chanate basin could extend from about Santa Ana to Sierra La Gloria, and probably as far as Sonoyta. The age of these basins is Coniacian?-Maastrichtian (Taliaferro, 1933; Lucas and González-León, 1990; Pubellier, 1987) but some could be somewhat older.

El Chanate Group is a continental deposit with an unknown extent; to the east it appears to pinch out near the Cerro La Pima area and to the northwest it could extend as far as Sonoyta, into southeastern Arizona and even as far as southeastern California where the McCoy Mountains Formation (Harding and Coney, 1985) is exposed.

El Chanate Group has great thickness variations over relatively short distances. Its greatest known thickness, about 2,800 m, is in the northern Sierra El Chanate. The units in the type locality may be absent in other areas. All these variations suggest a great tectonic instability resulting from ongoing orogenesis.

The Pozo Duro Formation, an upward-fining clastic sequence characterized by mudstone, sandstone and conglomerate, was deposited by meandering rivers draining an area to the southwest. Upward diminution of grain size suggests that, with time, the region became leveled.

Volcanic rocks at the base of the Anita Formation are the result of the re(?)-initiation of arc volcanism. The volcanic center serving as a source for the flows in the area is thought to have been not far to the east because the thickness and abundance of flows increase in that direction. Other volcanoes of this age have not been reported in the region. The thick wedges of andesite conglomerate (lower middle member) suggest an increase in relief, due mainly to the building of volcanic edifices. The area was largely leveled by the end of the middle member, characterized by mud-dominated upward-fining cycles deposited in meandering rivers. Near the end of Anita time black shales were deposited in a fresh water lake. Worth mentioning is the description of Hayes and Drewes (1978, p. 205) of part of the Fort Crittenden Formation in the Santa Rita Mountains, southeastern Arizona: "... a lenticular conglomerate made up of dominantly well rounded cobbles of lower Mesozoic volcanic and sedimentary rocks. Above this is a 160-m-thick sequence of gray shale and subordinate siltstone in which are found varied fauna, including fresh water mollusks, fish, turtles and dinosaurs of Santonian to Maastrichtian age (Miller, 1964). Above this fossiliferous shale unit in the Adobe Canyon area is more than 1,800 m of variable grayish red and brown conglomerate, arkosic sandstone and subordinate shale. High in the unit are several thin rhyolitic tuff beds". This suggests that the depositional environments in both areas were very similar, even though basin connection seems unlikely.

The thickness of the Anita on the northern side of the Sierra El Chanate is several times that on the southern side, suggesting that the basin was compartmentalized and elongate in a northwest-southeast direction.

The Escalante Formation was deposited in an alluvial basin: the lower member by alluvial fans, braided streams and finally in meandering rivers. The upper member, a succession of sandstone and shale couplets, was deposited in a lake delta. At the end of Escalante deposition nearby volcanic activity is indicated by thin intercalations of rhyolitic tuffs.

The Altar Formation (García y Barragán *in* Jacques-Ayala, Alencáster and Buitrón, 1990; García y Barragán, 1992) was deposited in alluvial fans adjacent to the source, probably representing very rapid, geologically instantaneous, deposition. The formation appears to be geographically restricted, so it could have been shed into a small, rapidly subsiding basin. The source of the detritus was most probably the Jurassic continental volcanic arc, which includes quartz arenites, as well as quartz sandstone cobbles and boulders. An alternative source could be the Proterozoic-Paleozoic of the Caborca block mixed with ryholitic to andesitic volcanic rocks derived from the Jurassic or Alisitos arcs. An argument against this source is the absence of dolomite and limestone clasts, which make up most of the stratigraphic column of the Caborca block.

As this unit shows the strongest deformation in the area, it is thought to be a thrust-front deposit that was subsequently overrun and deformed by the thrust plate (García y Barragán *et al.*, 1991).

DISCUSSION

The El Chanate Group of northwestern Sonora is a continental sequence of Late Cretaceous age, deposited with erosional unconformity on the Lower Cretaceous Bisbee Group. It is divided into three formations: the Pozo Duro (oldest), Anita and Escalante (youngest). Each of these units forms an upward-fining cycle with distinctive clast types in each of the conglomerates: quartz-sandstone (oldest), andesite, and rhyolite-andesite (youngest). The El Chanate Group varies significantly in thickness in relatively short distances: from 2,800 m on the northern limb of the mountain to 700 m on the southern limb. These variations, plus facies changes, suggest a compartmentalized basin in a tectonically active regime. The extent of the El Chanate basin is unknown at present. To the east it reached as far as Cerro La Pima, and seems to be present to the north, in the Sierra de Magdalena (Nourse, 1989). To the west, it may extend as far as Sonoyta, where thick conglomerates and sandstones with associated volcanics are exposed. These have been assigned a Jurassic age, mainly on the basis of their deformation, stretching and metamorphism (Corona, 1979, 1989; Caudillo-Sosa *et al.*, 1996; Connors *et al.*, 1989). However, in the Sierra El Batamote, conglomerates strikingly similar to the El Chanate Group and stratigraphically below the Tarahumara Formation display the same type of deformation, suggesting that those to the west could also be Late Cretaceous. If this is correct, then the El Chanate basin would be relatively large. Additionally, in southwestern Arizona and southeastern California are isolated exposures of clastic sequences (McCoy Mountains Formation and equivalents) which were thought to be entirely Jurassic. The lower part of the McCoy Mountains Formation is now known to be Late Jurassic whereas the upper part is as young as Late Cretaceous (Stone *et al.*, 1987). Hence, the presence of the Bisbee and El Chanate groups in northwestern Sonora may have a bearing on the McCoy Mountains Formation and correlative units of southeastern California and southwestern Arizona (Harding and Coney, 1985; Tosdal *et al.*, 1989). The Cretaceous sequence in Caborca probably represents the link between the McCoy Mountains and the Bisbee and Fort Crittenden/Cabullona basins in southeastern Arizona and northeastern Sonora.

The identification of undeformed and deformed Upper Cretaceous rocks in the Caborca area is of great importance because it modifies current reconstructions of events during the Mesozoic; particularly the hypothesis of the Mojave-Sonora megashear. The metamorphic belt along which the trace of the megashear was proposed is not Jurassic in age but latest Cretaceous and early Tertiary, as indicated by stratigraphic and isotopic-age criteria. Regional trends in bedding and foliation attitudes in rocks of diverse ages, from Proterozoic (Calmus and Sosson, 1995) to Lower and Upper Cretaceous (McComb, 1987; Harrar, 1989; Jacques-Ayala, 1993) clearly suggest that both were formed under the same type and direction of deformation. Additional support is provided by sedimentologic data, as the provenance study of the Bisbee Group in northwestern Sonora (Jacques-Ayala, 1995), that indicates that the source area was a volcanic terrane, mainly rhyolitic, and not the Proterozoic-Paleozoic rocks of the Caborca terrane. Furthermore, sediments derived from the Caborca terrane occur at the base of the Upper Cretaceous La Palma Formation (González-León and Jacques-Ayala, 1988) in the Cerro de Oro area, more than 100 km southeast of the Sierra El Chanate. This suggests that in the early Late Cretaceous the Caborca block was probably advancing as a thrust sheet from south-southwest to north-northeast.

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APPENDIX: DESCRIPTION OF SECTIONS

Section 1. The section was measured along a gully on the southwestern side of the Sierra El Chanate (Figure 5). It can be reached driving along a road that begins on Highway 2, at the Ejido 16 de Septiembre, goes to the Pozo Duro Ranch and El Batamote mine (abandoned). The road crosses the gully about halfway to the sierra. All sections were measured using a 30 m tape in 2 m intervals. As most of the sequence is vertical to subvertical true thickness could be measured directly in the field.

Escalante Formation, Upper member

Unit		*Thick.* (m)	*Total*
1.	Sandstone, green, thin to medium bedded, fine to very fine grained, is intercalated with poorly exposed green shale in medium beds. Covered contact with	17	17
2.	Sandstone, green but weathers buff, thick bedded, evenly laminated, and with tangential and planar cross lamination. Is coarse to medium grained and pebbly. Locally contains conglomerate lenses made of angular fragments up to 2 cm in diameter. Covered contact with	8	25
3.	Sandstone, green, weathers in ball and pillow (?) structure, medium to thick bedded, coarse to fine and very fine grained, is intercalated with green shale. Locally displays tangential and planar cross lamination. Sharp contact with	24	49
4.	Sandstone, green, thick bedded with parallel and cross lamination (tangential and planar), and medium to coarse grained and pebbly. Sharp contact with	5	54
5.	Sandstone, green, medium bedded, intercalated with green, thin bedded, shale (2 m thick). Grades down into a green medium-bedded shale, with very thin intercalations of green sandstone, which become thicker toward the bottom (2-m thick). Grades in turn into a green, medium bedded, medium- to coarse-grain sandstone, with some pebbly layers and tangential cross lamination 1 to 2 cm thick. Transitional contact with	6	60
6.	Sandstone, green, thick bedded with planar and tangential cross lamination, coarse to medium grained. Toward the base are intercalations of green, thin- to medium-bedded shale, and the sandstone becomes thinner. Sharp irregular contact with	4	64
7.	Shale, green and rarely red, thin to thick bedded, with green, thin- to medium-bedded, fine-grained sandstone intercalations. The shale/sandstone contact is transitional, whereas the opposite is sharp, regular to irregular. The sandstone beds group together with thin interlayers of shale. The base of the unit is formed by a green, medium-grained sandstone. Sharp irregular contact with	21	85
8.	Sandstone, purplish buff, medium bedded with faint planar and cross lamination, medium to coarse grained with some pebbly veneers. Is intercalated with red, thin bedded shale. Sand size increases upward. Transitional contact with	8	93
9.	Shale, red, foliated, with small calcareous nodules and few thin intercalations of fine-grained, slightly bioturbated, sandstone. Units 8 and 9 form a coarsening upward cycle. Sharp irregular contact with	5	98
10.	Shale, green, foliated, thin to very thick bedded, is intercalated with some medium beds of medium grained sandstone. Sharp contact with	14	112
11.	Sandstone, green to greenish buff, thick bedded, medium to coarse grained, is intercalated with some thin beds of conglomerate. Sharp contact with	5	117
12.	Tuff, light green, thin to medium bedded, medium grained. Sharp contact with	4	121
13.	Sandstone, same as in Unit 11, but in the lower half the conglomerate becomes predominant. Sharp erosional(?) contact with	18	139
14.	Sandstone, greenish buff, thin bedded, is intercalated with dark gray to black shale in thin to thick beds. Poorly exposed. In transitional contact with	8	147
15.	Sandstone, green, medium to thick bedded, coarse to medium grained and pebbly, is intercalated with green, medium-bedded shale. Toward the lower half the conglomerate becomes more abundant, and color changes to purplish buff. Upper part of unit is poorly exposed	30	177
	Covered contact with the	12	189

Escalante Formation, Lower member

1.	Sandstone, purplish buff, thin to medium bedded, medium grained, is intercalated with thin-bedded shale, and some lenses and beds of polymictic conglomerate made of subangular to rounded fragments. Toward the bottom of unit, the shale dissapears, and the conglomerates become tabular. Transitional contact with	25	25
2.	Sandstone, green, medium to thin bedded, medium to coarse grained, is intercalated with thin- to medium-bedded conglomerate made of subrounded to rounded fragments. The basal 2.5 m are formed by a green, polymictic conglomerate. Fault contact with	16	41
3.-	Mudstone, red, thin to medium bedded, slightly sandy, is intercalated with red, medium- to thick-bedded shale with some very thin limestone lenses and calcareous nodules. The mudstone displays some faint bioturbation. Transtional contact with	23	64
4.	Sandstone, red, thin bedded, fine grained, is intercalated with red, thin- to medium-bedded shale and siltstone. Grades down into a red, thick-bedded, medium- to coarse-grained sandstone less than 2 m thick, which in turn grades into a thin-bedded conglomerate. Unit forms an upward-fining cycle. Sharp erosional contact with	5	69
5.	Same as in unit 4	7	76
6.	Same as in unit 4	6	82
7.	Same as in unit 4	8	90
8.	Same as in unit 4. Sandstone 75%; shale 25%	6	96
9.	Shale (80%), red, thick bedded, foliated, contains calcareous nodules and calcite, is intercalated with red, thin- to medium-bedded, fine-grained sandstone (20%). Sharp regular contact with	13	109
10	Sandstone (60%), green, thick bedded, medium to coarse grained and pebbly, is alternating with green, lenticular to tabular, polymictic conglomerate (40%). The clasts are angular to rounded. Rare intercalations of shale. Sharp regular contact with	11	120

11.	Shale (85%), red, thick to very thick bedded, homogeneous, foliated, contains calcareous nodules, disseminated as well as concentrated along bedding planes, is intercalated with red, thin- to medium-bedded, fine-grained, slightly bioturbated, sandstone (15%). The sandstone becomes more abundant toward the bottom. Sharp irregular contact with	19	139
12.	Sandstone, purplish gray, thick bedded, medium to coarse grained, with some intercalations of rip-up clast conglomerate. Sharp irregular contact with	8	147
13.	Sandstone, red, thin bedded, fine grained, is intercalated with red, medium-bedded, foliated shale. The base has a green, medium-bedded shale. Transitional contact with .	2	149
14.	Sandstone, red, thick bedded, medium to coarse grained, includes red, very thick, polymictic conglomerate lenses. The clasts are angular to rounded. Toward the base the conglomerate dissapears, suggesting a coarsening upward cycle. Sharp contact with	12	161

Pozo Duro Formation

1.	Shale (90%), red, homogeneous, contains calcareous nodules and is foliated; has intercalations of red, thin-bedded sandstone and siltstone (10%). Base of unit is poorly exposed.	25	25
Covered	....	26	51
2.	Shale, red, with calcareous nodules, is intercalated with red, thick- to medium-bedded sandstone. Unit is fractured and partially covered by caliche. Fracturing increases near base	32	83
Covered	....	5	88
3.	Shale, red, intercalated with red, medium to thin bedded sandstone. Poorly exposed. Unit similar to 33.	14	102
Covered	....	14	116
4.	Sandstone, grayish green, medium bedded, coarse to medium grained and conglomeratic. Thin lenses of conglomerate made of rounded to subrounded pebbles of quartz sandstone. Top of unit is mainly fine grained. Sharp irregular contact with	5	121
5.	Shale, red and foliated; grades down into a gray, thick bedded, medium grained to pebbly sandstone. The base of the unit is a 30 cm-thick conglomerate lens. Pebbles are rounded, and consist of quartz sandstone	5	126
6.	Same as in unit 5	4	130
7.	Same as in unit 5, but shale is 2-m thick	9	139
8.	Sandstone, gray, thick bedded, conglomeratic. Top of unit consists of red, medium grained sandstone. Sharp irregular contact with	8	147

Cintura Formation of the Bisbee Group

Section 2. This section was measured along a gully located on the southern rim of the sierra, 2.2 km north of the El Batamote Mine (Figure 5). The gully can be reached by the road that goes from Rancho Pozo Duro toward the northwest, to the El Batamote, always taking the road to the right. Before getting into the Sierra El Chanate toward section I, the road forks to the right, crosses a gully and goes eastward uphill. The road ends at the gully, where there is an old miner's mill that belonged to Mr. Antonio Celaya, from Altar.

Escalante Formation, Upper member

Unit		Thick. (m)	Total
1.	Sandstone, greenish brown, thin bedded, fine grained, is intercalated with greenish buff shale in thin beds. In transitional contact with	3	3
2.	Sandstone, gray, massively bedded with plane parallel and cross lamination, medium to coarse grained. Includes several very thin beds of conglomerate. Sharp contact with	4	7
3.	Sandstone (50%), brownish gray, medium to very thick bedded, medium grained, is intercalated with greenish gray, medium- to very thick-bedded, locally fissile, shale (50%). Transitional contact with	11	18
4.	Sandstone, greenish gray, very thick bedded with plane parallel and cross lamination, medium to coarse grained. Sharp regular contact with	4	22
5.	Shale, purple, homogeneous, foliated, is intercalated with purple, medium- to thin-bedded, medium-grained sandstone. In the upper half of the unit, the sandstone is predominant, suggesting an upward coarsening sequence. Sharp irregular contact with	6	28
6.	Sandstone (70%), olive green but weathers in ocher, thick bedded, coarse to medium grained, displaying graded bedding; some beds have a pebbly base, or conglomerate lenses. It alternates with green, medium- to thin-bedded, foliated shale (30%). Few small faults cut the unit	21	49
Covered	....	17	66
7.	Sandstone (75%), grayish purple, thin to medium bedded, coarse to medium grained, locally with small conglomerate lenses, alternating with purple, thin-bedded shale (25%)	5	71
Covered	....	40	111
8.	Conglomerate, purplish gray to mottled, massive, clast-supported, polymictic, made of subangular to rounded pebbles as large as 10 cm, but predominating those smaller than 2 cm. The matrix is sandy. Sharp irregular contact with	7	118
9.	Sandstone, red, thin bedded, fine grained, alternating with red, thin-bedded-shale. Transitional contact with ...	4	122
10.	Sandstone, gray, thick bedded, coarse grained and pebbly, includes conglomerate lenses as thick as 3 m. Covered contact with	14	136
11.	Mudstone, purple, thick bedded, with thin intercalations of purple, medium grained sandstone. Grades down into a purple, 1.2 m-thick, medium-grained sandstone. Sharp contact with	9	145

Escalante Formation, Lower member

1.	Shale, ocher green, massive and foliated. Transitional contact with	10	10
2.	Sandstone, purple to red, structureless, medium to coarse grained, with intercalated conglomerate lenses. Transitional contact with	11	21
3.	Conglomerate, mottled, polymictic and clast-supported; clasts are subangular to rounded, as large as 15 cm in diameter, but those smaller than 1 cm are predominant. Sharp, erosional contact with	2	23
4.	Shale, green to gray, massive and foliated. Transitional contact with	3	26
5.	Sandstone, purple, medium bedded with parallel lamination, medium grained. Sharp contact with	9	35
6.	Mudstone, purple to red, with intercalations of fine- to medium-grained sandstone. Unit is thick to very thick bedded. Grades down into	29	64
7.	Sandstone, purplish gray, medium to thin bedded, medium grained. Upper part includes interbeds of mudstone. Sharp irregular contact with	4	68
8.	Mudstone, red, thick to very thick bedded, with thin intercalations of gray, medium- to fine-grained sandstone. Transitional contact with	12	80

9.	Sandstone, purplish gray, medium bedded with thick plane-parallel laminations, and medium grained. Sharp contact with	11	91
10.	Shale, red, thick bedded, foliated. Transitional contact with	3	94
11.	Sandstone, grayish green to grayish purple, thick bedded, coarse to pebbly; grades upward into an alternation of coarse- to medium- and fine-grained sandstone and siltstone. Sharp irregular contact with	12	106
12.	Siltstone, purple, thick to very thick bedded, intercalated with green to purple, thick-bedded, medium- to coarse-grained sandstone. Sandstone is lenticular to tabular. The sandstone/siltstone contacts are sharp and erosional. Siltstone contains calcareous nodules. Sharp contact with	18	124
13.	Sandstone, purple, thick bedded, fine to medium grained, with thin intercalations of coarse to pebbly sandstone. Sharp contact with	13	137
14.	Sandstone, grayish green, thick bedded, coarse to pebbly which grades down into a clast-supported, polymictic conglomerate. Clasts are rounded, and can be as large as 8 cm in diameter. Sharp irregular contact with	3	140
15.	Sandstone, green to purple, medium to thick bedded, medium grained, intercalated with purple, thick-bedded mudstone and shale. Sharp irregular contact with	12	152
16.	Shale, purple, thick bedded with some calcareous nodules, is intercalated with green, thick-bedded, medium-grained sandstone. Sandstone becomes predominant in the lower half of unit. Sharp irregular contact with	16	168
17.	Shale, green, massive and foliated. Transitional contact with	6	174
18.	Sandstone, gray, medium bedded, and coarse to medium grained. It has intercalations of conglomeratic lenses. The base if formed by a conglomerate lens made of rounded clasts not larger than 3 cm. Sharp, erosional contact with	8	182
19.	Shale, red, massive, with some calcareous nodules. Grades down into a red, 1 m-thick, fine-grained and shaley sandstone, which in turn grades down into a 1 m-thick, coarse-grained sandstone and conglomerate. The conglomerate is grain-supported, and the pebbles are rounded. Sharp irregular contact with	7	189
20.	Mudstone, red, medium to thick bedded, is intercalated with red, medium bedded, medium-grained sandstone. Poorly exposed. Sharp irregular contact with	21	210

Anita Formation

1.	Andesite, green but weathers in ocher greenish, porphyritic with plagioclase phenocrysts. Toward the top there are small amphibole phenocrysts. The uppermost 5 meters consist of an andesite breccia in which the matrix and the clasts are of the same material, suggesting a lava flow	56	56

Pozo Duro Formation

1.	Shale, red, massive, grades down into a 1 m-thick, gray, medium to coarse grained sandstone. Sharp contact with	7	7
2.	Andesite sill, green but weathers in ocher, porphyritic with plagioclase and amphibole phenocrysts. Sharp contact with	4	11
3.	Sandstone, light gray to purplish gray, medium to thin bedded, coarse grained and pebbly. Few intercalations of red, thin-bedded mudstone. Sharp irregular contact with	19	30
4.	Shale, green and massive. Poorly exposed. Covered contact with	3	33
5.	Sandstone, brownish gray, weathers in buff and in "ball and pillow" structures, medium bedded and medium grained. Covered contact with	8	41
6.	Siltstone, red to purplish red, sandy, massively bedded and with rare calcareous nodules. Becomes sandier downward. Transitional contact with	20	61
7.	Sandstone, buff, thick bedded, medium to coarse and pebbly. Grain size increases downward. A white, less than 1-m thick, laterally discontinuous bed of a fine grained sandstone is intercalated. Transitional contact with	15	76
8.	Sandstone, buff, thick to very thick bedded, coarse to medium grained and pebbly. Has intercalations of conglomerate lenses. These are grain-supported, polymictic, and of rounded clasts. Sharp erosional contact with	6	82
9.	Mudstone, purple to purplish red, thin bedded, intercalated with purple to purplish red, thin-bedded, fine-grained sandstone. Transitional contact with	2	84
10.	Sandstone, buff, thick bedded and medium to coarse grained. Transitional contact with	7	91
11.	Sandstone, gray to purplish, medium to thick bedded, coarse to medium grained. Unit capped by a 1.5 m-thick, red mudstone with some calcareous nodules and bioturbation	18	109
12.	Sandstone, gray, very fine grained and structureless. It has green calcareous nodules that weather in buff. Unit has concretions with a concentric structure	3	112
Covered		8	120
13.	Same as in unit 12	7	127
Covered		9	136
14.	Same as in unit 12. Sharp contact with	3	139
15.	Sandstone, gray, medium bedded, medium to fine grained, with thin intercalations of purplish gray mudstone. Unit is poorly exposed. Covered contact with ..	6	145
16.	Mudstone, purple, thin bedded, medium grained and bioturbated. Is intercalated with gray, thin- to medium-bedded, medium grained sandstone. Unit is poorly exposed	14	159
17.	Sandstone, cream-colored, thick bedded with thick laminations, coarse to medium grained and pebbly. The pebbles are rounded and made of quartz-arenite. Sharp irregular contact with	10	169
18.	Mudstone, red to purplish red and massive. Thick lamination and bioturbation can be observed locally, especially near the top of the unit. It has calcareous nodules and is foliated. There are intercalations of gray to purplish gray, fine-grained sandstone. Toward the middle of unit there are interlayered lenses of white, medium- to coarse-grained quartz sandstone. Lenses are about 40 cm thick and less than 2 m wide. Unit is poorly exposed. Transitional contact with	54	223
19.	Sandstone, purplish gray, medium grained. Transitional contact with	2	225
20.	Sandstone, white, medium bedded, coarse to medium grained and pebbly. Pebbles are rounded to well rounded and made of quartz-arenite. Sharp irregular (erosional?) contact with	4	229

Cintura Formation of the Bisbee Group

Section 3. The section is located along a gully on the southern rim of the Sierra El Chanate, toward its eastern end. It can be reached by the road that goes southeastward from the El Batamote Mine and a hard-to-follow road that goes to the north. The junction is on the arroyo just before the fence of the ranch and a locked gate. Its Mercator coordinates are X = 415,300 and Y = 3'405,020.

Escalante Formation, Upper Member

Unit		Thick. (m)	Total
1.	Sandstone, purplish gray to gray, thick to very thick bedded with no internal structure, and medium to coarse grained. It is interbedded with purple, medium-bedded shale. Toward the top, the sandstone has locally a pebbly base and few conglomerate lenses. Exposure is largely covered by debris from the overlaying Tarahumara Formation	142	142
2.	Shale, olive green, medium to thick bedded and foliated, is intercalated with olive green to brownish green, medium- to thick-bedded, medium- to coarse-grained sandstone. There are few intercalations of medium-bedded red shale. Stromatolitic limestone lenses, 10 to 15 cm thick and less than 1 m long occur in the upper part of the unit. Bedding becomes thinner downward. Transitional contact with	38	180
3.	Shale, olive green, massively bedded and foliated. Transitional contact with	8	188

Escalante Formation, Lower Member

1.	Sandstone, brownish green, medium to thick bedded, coarse grained and pebbly, is intercalated with olive green, medium-bedded, shale. In the lower half of the unit the amount of shale diminishes. Covered contact with	50	50
2.	Sandstone, greenish buff, thick bedded and medium to coarse grained. Thickness and grain size increase toward the base, which is formed by a polymictic conglomerate. Clasts are rounded and mostly volcanic. Locally there are interbedded lenses of andesitic volcanic breccias. Covered contact with	31	81
3.	Mudstone, red to purplish red, thick bedded, locally in thin beds or bioturbated. Few gray, thin-bedded, medium-grained sandstone. Covered contact with	9	90
4.	Mudstone, purplish red to red, very thick bedded, locally with plane parallel and wavy lamination and thin bedding and bioturbation. Few intercalated lenses of red, medium- to coarse-grained, sandstone. Also, there are interbeds of rhyolitic tuff; it is greenish-white, medium- to thick-bedded, aphanitic and with flow structures. Outcrop is poorly exposed.	69	159
Covered		21	180
5.	Sandstone, olive to grayish green, in thick beds, some of which display plane-parallel lamination, and medium grained. It is intercalated with red to purplish red, medium- to thin-bedded, mudstone. Few conglomeratic sandstone lenses are present.	20	200
6.	Mudstone, red to purplish red, thick to very thick bedded and locally shaley (some beds are made entirely of shale). Is intercalated with olive green to gray, thick- to medium-bedded, coarse- to medium-grained sandstone. Some sandstones are pebbly to conglomeratic. Conglomerate lenses are also present. They are clast-supported, and consist of rounded clasts of volcanic rocks. The finer fraction makes about 60% of the unit, sandstone about 35% and the conglomerate an estimated 5%. Outcrop is poor. Sharp regular contact with	83	283

Anita Formation

1.	Andesite, dark brownish red to purplish red, aphanitic with plagioclase phenocrysts. Locally it is a breccia made of angular fragments and matrix of the same andesite. No stratification is observed. Small red and angular fragments, probably glass, occur throughout. Unit shows fracturing filled by quartz and Fe oxides(?)	101	101

Pozo Duro Formation

Covered		5	5
1.	Shale, red, massively bedded with interbedded red siltstone and fine-grained sandstone. Strongly fractured and altered, as if it were a fault zone	18	23
Covered		32	55
2.	Sandstone, gray, thick bedded, medium to coarse grained and pebbly, forming upward-fining cycles. Pebbles are rounded to well rounded, not bigger than 2.5 cm in diameter and made of volcanic rocks. Sharp irregular contact with	3	58
3.	Shale, red to purplish red, thin bedded, intercalated with red, thin-bedded, fine-grained sandstone. Grades down into a 2-m thick, thick-bedded, medium- to coarse-grained and pebbly sandstone. Sharp irregular contact with	7	65
4.	Shale, as in unit 3 but, poorly exposed. Grades down into a sandstone as in unit 2.	7	72
Covered		19	91
5.	Sandstone, purplish gray but weathers in very dark gray, medium to thick bedded, coarse to medium grained.	3	94
Covered		34	128
6.	Sandstone, light gray, massively bedded, medium to coarse grained and pebbly. Sandstone is quartz-rich and pebbles are rounded to well rounded quartz-arenites. Sharp irregular contact with	3	131
7.	Shale, green to grayish green, poorly exposed	5	136
8.	Sandstone, grayish green, thick bedded, coarse to medium grained, with intercalations of greenish white, clast-supported conglomerate lenses. Sandstone is quartz-rich, and the pebbles in the conglomerate are made of quartz-arenite.	13	149
9.	Shale, red, massively bedded, with disseminated calcareous nodules. Transitional contact with	6	155
10.	Sandstone, green to purplish red, thick bedded, fine to medium grained and lithic rich. Top of unit has intercalations of red shale. Covered contact with	5	160
11.	Shale, red, massively bedded, locally bioturbated. Exposure is poor.	7	167
12.	Sandstone, olive green, thick bedded, coarse to medium grained and lithic rich. Covered contact with	10	177
13.	Shale, purplish red, barely exposed.	6	183
14.	Sandstone, olive green but weathers in blackish green, thick bedded and coarse to medium grained.	4	187
Covered, but red shale can be observed as regolith		10	197
15.	Sandstone, gray, thick bedded, coarse to medium grained with intercalated conglomerate lenses. Grades up into a non-pebbly sandstone. Sharp irregular contact with	11	208

Cintura Formation of the Bisbee Group.

Section 4. The section was measured on the northern side of the range (Figure 5), along a gully, except for the uppermost part which was measured on the eastern side of the gully. This gully can be reached by the dirt road that goes from Altar to the San Jacinto and Los Chirriones ranches, 1.1 km beyond the junction with the road that crosses the Arroyo Sásabe. The lower part of the section can be found by walking southward along the gully. Another way is taking an unimproved road that leaves the main dirt road south of the junction, along a "detour" to the old road. It crosses a gully and goes through the small, elongate hills that mark the base of the Pozo Duro Formation.

Escalante Formation, Upper member

Unit		Thick. (m)	Total
1.	Sandstone, olive green to greenish orange, thick to very thick bedded, fine grained to silty. Is intercalated with olive green to greenish gray, thin-bedded, coarse-grained to pebbly sandstone. Few of these sandstones are in very thick beds. Near the base there are intercalations of medium-bedded, gray shale; the sandstone becomes dark gray. Thin beds of white rhyolitic tuff, similar to the very thick ones at the base of the overlying Tarahumara Formation, are locally present. The unit coarsens upward.	195	195
2.	Sandstone, olive green but weather in buff, parallel and crossed lamination, fine grained. Lamination is enhanced by the alternation of layers with and without calcareous cement. This causes a rugose texture in outcrop. Sharp contact with the	12	207

Escalante Formation, Lower member

1.	Sandstone, grayish purple, medium bedded and medium grained, which grades down into a purple, thick bedded conglomerate 7 m thick. The conglomerate consists mostly of subrounded clasts of volcanic rocks and sandstone. Sharp contact with	9	9
2.	Sandstone, purplish gray, medium to thick bedded, medium grained. Some beds display very thin parallel lamination. Few intercalations of purplish gray conglomerate lenses made mostly of subrounded clasts derived from volcanic rocks. Covered contact with	79	88
3.	Conglomerate, purplish gray to green, clast-supported, and in thick to very thick lenses. It consists of rounded, irregularly shaped clasts, mainly of volcanic rocks. Intercalated sandstone is purplish gray to green, thick bedded, coarse to medium grained and pebbly. Some fragments are rip-up clasts from the underlying siltstone. Some beds display parallel and cross lamination. Also intercalated is a green, medium-bedded siltstone, some of which includes black silicified wood fragments. Covered contact with	24	112
4.	Sandstone, olive green, thick bedded locally with faint lamination and coarse to medium grained. Some beds have a conglomeratic base. There are intercalations of red, thin-bedded, fine-grained sandstone to siltstone. Covered contact with	14	126
5.	Siltstone, red, medium bedded with thin intercalations of red, fine-grained sandstone and shale. Poorly exposed. .	9	135
6.	Sandstone, purplish gray to green, thick bedded, coarse to medium grained. There are thin intercalations of sandy siltstone and conglomeratic lenses. Sharp irregular contact with	20	155
7	Siltstone, red, medium to thin bedded, with thin intercalations of red shale. It is 4-m thick. Transitional contact with	9	164
8.	Sandstone, gray, medium bedded, coarse to medium grained, with intercalations of purplish gray lenses of conglomerate. The conglomerate consists of angular to rounded clasts of volcanic and sedimentary rocks. Sharp erosional contact with	4	168
9.	Sandstone, gray, thick bedded with lamination, medium grained, intercalated with thin-bedded siltstone. Base of unit is formed by a gray, 0.7-m-thick conglomerate. It consists of rounded to angular volcanic and calcareous clasts, mostly less than 2 cm in diameter. Sharp erosional contact with	4	172
10.	Sandstone, green to purplish green, medium to thin bedded, medium to fine grained, with intercalated lenses of coarse-grained to pebbly sandstone and thin-bedded siltstone. Sharp irregular contact with	5	177
11.	Shale, green, very thick bedded, with some disseminated calcareous nodules, and foliated. Some thin intercalations of green siltstone. Transitional contact with	9	186
12.	Sandstone, red, structureless, medium to fine grained, with a shaley matrix and some calcareous nodules. Some of the nodules have been dissolved, leaving a void. Unit is partially bioturbated. Sharp contact with	12	198
13.	Sandstone, gray, thick bedded with thin lamination, and coarse to medium grained. Is interbedded with green, thick-bedded, foliated shale. Sharp contact with	17	215
14.	Shale, gray, thick bedded, with calcareous nodules, is intercalated with medium-bedded siltstone. Transitional contact with	17	232
15.	Sandstone, purplish gray to gray, medium bedded, medium to fine grained with voids caused by the dissolution of calcite nodules. Sandstone is strongly bioturbated. Conglomerate lenses are intercalated, especially toward the bottom of unit.	18	250
16.	Sandstone, purplish gray to gray, medium bedded, is intercalated with gray, medium-bedded siltstone. Poorly exposed.	22	272
17.	Sandstone, gray, medium to coarse grained, is intercalated with purple, medium to thick bedded, fine grained sandstone. Few conglomeratic sandstone lenses occur. Sharp regular contact with	4	276
18.	Siltstone, red, medium to thick bedded, is intercalated with gray, medium- to thick-bedded, and medium- to fine-grained sandstone. Toward the bottom the sandstone becomes coarser and has intercalations of volcanic-clast conglomerate lenses.	28	304
19.	Sandstone (60%), red, medium to thick bedded, coarse to medium grained. Graded bedding is common, with a pebbly sandstone or conglomerate at the base. It is interbedded with red, medium-bedded siltstone (30%). Also present are some small conglomerate lenses made of volcanic fragments and rip-up clasts. Laterally, siltstone becomes predominant. Sharp contact with	8	312
20.	Sandstone, gray, coarse to medium grained (conglomeratic near the base). Locally it displays thin plane-parallel stratification. It has intercalations of thin conglomerate lenses. Laterally the conglomerate becomes predominant. Sharp regular contact with	5	317
21.	Sandstone, gray, thin bedded, fine grained, and bioturbated; is intercalated with red, thin-bedded, and foliated shale. Grades down into a 1 m-thick, gray, thinly-bedded sandstone. Sharp regular contact with	14	331
22.	Sandstone, purplish gray, medium bedded and fine grained, is intercalated with green, medium-bedded shale. The base has abundant very small calcareous nodules. Transitional contact with	4	335
23.	Sandstone, purple, medium bedded with thin laminae, coarse to medium grained and pebbly. Interbeds of fine-grained sandstone are present. Few intercalations of volcanic-clast conglomerate lenses, especially at the base. Sharp erosional contact with	6	341
24.	Shale, red, massively bedded, with calcareous nodules. Few intercalations of red, thin-bedded siltstone. Transitional contact with	6	347
25.	Sandstone, gray, coarse to medium grained, with thin conglomerate lenses. It grades down into lenses of mottled to purple conglomerate of rounded volcanic rock fragments. Some interbeds of coarse-grained sandstone. Sharp erosional contact with	6	353

26.	Sandstone, purplish gray, medium bedded, fine grained, is intercalated with purple, medium bedded-shale. Unit fines upward. Transitional contact with	13	366
27.	Sandstone, greenish gray to gray, medium bedded with parallel and cross lamination, medium to coarse grained, is intercalated with coarse-grained to pebbly sandstone. The base is formed by a 0.6 m-thick conglomerate made of rounded volcanic rock fragments in a greenish gray sandy matrix. Unit fines upward.	14	380
28.	Sandstone, green to purplish green, medium bedded, is intercalated with medium-bedded mudstone. Exposure is poor.	19	399
29.	Conglomerate, red, massive, no bedding features were observed; clasts are well rounded to subangular, and are made of volcanic (mostly) and sedimentary rocks. Unit is capped by an alternation of red, thin-bedded sandstone and shale less than 1-m thick.	19	418
30.	Sandstone, green, medium to thick bedded, medium to fine grained and shaley, locally with abundant calcareous nodules concentrated along bedding planes.	20	438
31.	Sandstone, red to greenish gray, medium bedded coarse to fine grained and pebbly, grade down into red, massively-bedded, foliated shale. Covered contact with	22	460
32.	Conglomerate (85%), mottled to purplish red, massively bedded, made mainly of volcanic (rhyolitic) rock fragments and subordinated sedimentary rocks. The clasts are well rounded to subangular, poorly sorted and with no preferential orientation. Intercalated sandstone (15%) is gray to red, thin bedded, coarse- to medium-grained and conglomeratic. Covered contact with	51	511

Anita Formation, Upper member

1.	Shale, purplish and greenish brown, massively bedded, with abundant calcareous nodules. These are irregular to spheroidal and as large as 30 cm. Grades upward into an ocher green, medium-bedded, medium- to coarse-grained sandstone. Covered contact with	15	15
2.	Sandstone, purplish gray, medium bedded, fine grained, is intercalated with red, medium-bedded siltstone. Both rock types have calcareous nodules up to 25 cm in diameter. Unit is cut by several vertical faults.	7	22
3.	Shale, green to red but weather in buff, medium to very thick bedded. Near the contact there are few interbeds of dark gray, thin-bedded micstone. Is intercalated with, medium- to thick-bedded, medium to coarse-grained and pebbly sandstone. Some sandstone displays inverse graded bedding. Shale increases downward, forming a coarsening-up sequence. Transitional contact with	196	218
4.	Shale, gray to dark gray but weathers in greenish and reddish buff, massively bedded. Has thin interbeds of dark gray limestone and sandstone. The limestone, which varies from micstone to wackestone, contains gastropods and pelecypods. Unit is cut by numerous small faults. Transitional contact with	12	230
5.	Shale, same as in unit 3. Has few intercalations of greenish to reddish buff, thin- to medium-bedded, rarely reach 1 m, and fine- to medium-grained sandstone. Transitional contact with	39	269

Anita Formation, middle member

1.	Sandstone, buff, thick to very thick bedded, medium to coarse grained and pebbly, with intercalations of medium-bedded conglomerate. Sharp erosional(?) contact with	15	15
2.	Sandstone, red, medium to thick bedded, medium to coarse grained and pebbly. Near the top there are interbeds of fine-grained sandstone and siltstone. Transitional contact with	43	58
3.	Sandstone, red, medium to thick bedded, medium to coarse grained and pebbly. Grain size diminishes upward. Sharp erosional contact with	10	68
4.	Sandstone, gray, medium to thick bedded, fine grained, is intercalated with red, medium- to thick-bedded shale. The shale contains calcareous nodules. Transitional contact with	17	85
5.	Shale, purplish red to red, thick bedded, with few intercalations of sandstone. Grades down into a gray, medium-bedded, medium- to fine-grained sandstone with some intercalated shale. Transitional contact with	9	94
6.	Sandstone, gray, medium bedded, medium grained, with intercalated red, thin-bedded shale. Grades down into the lower half, consisting of interbedded coarse-grained to pebbly sandstone and conglomerate. The pebbles are mostly of volcanic (andesitic) rocks. Units 4, 5 and 6 form an upward-fining cycle. Sharp erosional contact with	6	100
7.	Shale (75%), green and red, thick bedded, with intercalations of gray, medium-bedded sandstone (25%). Transitional contact with	9	109
8.	Shale (50%), green to red, thin to medium bedded, with intercalations of red, thin- to medium-bedded sandstone (50%). Transitional contact with	14	123
9.	Sandstone, red, medium to thick bedded, fine grained, is interbedded with red to green, thick-bedded shale with small calcareous nodules. Sharp contact with	23	146
10.	Sandstone, cream-colored, medium bedded, coarse to medium grained, is intercalated with purplish gray, medium-bedded conglomerate. Clasts in the conglomerate are rounded to subangular and mostly derived from andesite. Sandstone is quartz-rich. Sharp erosional contact with	5	151
11.	Siltstone, red, thin irregular bedding, and some bioturbation. Transitional contact with	3	154
12.	Sandstone, gray, medium bedded with parallel and cross lamination, medium to coarse grained and pebble. Is intercalated with medium-bedded conglomerate lenses. Conglomerate is mainly volcanic. Sharp erosional contact with	6	160
13.	Sandstone, gray, medium to thick bedded with plane-parallel lamination, planar and trough cross-lamination, medium to coarse grained and pebbly. Grades down into a volcanic conglomerate forming a lens with a maximum thickness of 1.2 m. Has some intercalated shale at the top. Erosional contact with	4	164
14.	Sandstone, gray, medium bedded with parallel and tangential cross lamination, is intercalated with volcanic-clast conglomerate. Some intercalated shale toward the top of unit. Sharp erosional contact with	4	168
15.	Sandstone, red, medium bedded, fine grained, is intercalated with red, thin-bedded shale. Few interbeds of cream-colored, medium-bedded with parallel lamination, medium-grained sandstone. This sandstone is quartz-rich, whereas the red sandstone is lithic-rich. Transitional contact with	10	178
16.	Sandstone, red, medium bedded, medium to coarse grained and pebbly, is intercalated with lenses of volcanic-clast conglomerate. Sharp contact with	3	181
17.	Shale, red, thick bedded to massive, has intercalations of red, thin-bedded, fine-grained sandstone. Transitional contact with	34	215

18.	Conglomerate, mottled, thick bedded, mainly of andesitic clasts, has intercalations of red, lenticular, medium- to coarse-grained and pebbly sandstone. Sharp contact with	4	219
19.	Shale, red to purplish red, medium to thick bedded, is intercalated with red, thin bedded, fine-grained sandstone. Transitional contact with	8	227
20.	Conglomerate, mottled to purplish red, very thick bedded, clast-supported in a sandy matrix. Clasts are rounded to subangular, and consist mainly of andesitic rocks. Some thin intercalations of medium-grained sandstone in thin beds with parallel and cross lamination. Unit is capped by a 0.8 m-thick sandstone with graded bedding. Sharp irregular contact with	10	237
21.	Shale, red, thin bedded, is intercalated with red, thin-bedded, fine-grained sandstone. Shale contains few calcareous nodules. Grades down into a 1 m-thick volcanic conglomerate. Unit is cut by several small faults. Covered contact with	7	244
22.	Shale, red, thick bedded, has few intercalations of red, thin-bedded, fine-grained sandstone. Sandstone increases downward. Base of unit is formed by a 2.2 m-thick volcanic conglomerate. Sharp irregular contact with	9	253
23.	Shale, red, very thick bedded, with calcareous nodules, is intercalated with red, thin-bedded, fine-grained sandstone.	23	276
Covered	....	12	288
24.	Shale and sandstone, as in unit 22, but base of unit is formed by a 1.6 m-thick conglomerate. Erosional contact with	8	296
25.	Shale (70%), purplish red, thick to very thick bedded, with interbeds of red, thin-bedded, medium- to fine-grained sandstone (30%). Some beds display faint bioturbation. Transitional contact with	25	321
26.	Sandstone, purplish gray, medium bedded, coarse to fine grained, grades down into a conglomerate of volcanic rock fragments. Erosional contact with	3	324
27.	Shale and sandstone, as in unit 22. Transitional contact with	7	331
28.	Sandstone, medium to thin bedded, medium to coarse grained and pebbly, has intercalations of conglomerate lenses. Erosional contact with	7	338
29.	Shale and sandstone, as in unit 22, but grades down into a 2-m thick, purplish red, coarse- to medium-grained and conglomeratic sandstone. Transitional contact with	10	348
30.	Sandstone and conglomerate, as in unit 28. Erosional contact with	3	351
31.	Shale (70%), red to green, thin to very thick and massively bedded with calcareous nodules concentrated along bedding planes. Is intercalated with red to green, medium- to thick-bedded, fine to medium and locally coarse-grained sandstone (25%). Lower contact of sandstone is sharp, whereas the upper one grades into the shale. There are few intercalated conglomerate lenses (5%). These consist of rounded to subangular volcanic clasts.	103	454
32.	Shale, red, thick bedded, foliated, is intercalated with red, thin-bedded sandstone, locally with thin parallel and cross lamination. Downward, the amount of sandstone increases becoming predominant. Few intercalated conglomerate lenses. The base of the unit is formed by medium-grained, medium-bedded sandstone and conglomerate lenses.	23	477
33.	Shale (85%) red, very thick to massively bedded is intercalated with red, medium- to fine-grained sandstone (15%). Sandstone increases downward. Sharp contact with	34	511
34.	Sandstone, red, medium to thin bedded locally with parallel and cross lamination, coarse to medium grained and pebbly. Is intercalated with mottled, lenticular conglomerate. The clasts are rounded to angular, can be as large as 20 cm but those between 1 and 2 cm are predominant, and consist mainly of gray to dark gray andesite, and minor sandstone and siltstone.	7	518
35.	Shale, red, thick to massively bedded, with intercalated red, medium-bedded with parallel and cross lamination, coarse- to fine-grained sandstone. The upper third of unit includes no sandstone layers. Covered contact with	10	528
36.	Sandstone, red, medium bedded, fine to medium to coarse grained and conglomeratic. Fine grained sandstone is tabular, with parallel and cross lamination, and is cut by a small conglomerate lens. Clasts can be as large as 30 cm, but those between 1 and 3 cm predominate. Erosional contact with	4	532
37.	Shale, red, thick to massively bedded, and foliated. Is intercalated with red, medium- to thick-bedded with parallel and cross lamination, fine- to medium-grained. Upper half of unit has almost no sandstone, whereas lower half has more sandstone and the shale becomes thinner. Transitional contact with	11	543
38.	Conglomerate, gray to red, polymictic, forming lenses. Clasts are rounded to angular, and consist of volcanic rocks, mostly andesitic. Few intercalations of pink, medium-bedded or forming lenses, and coarse-grained to pebbly sandstone. It has cross lamination and graded bedding.	5	548
Covered	....	52	600
39.	Conglomerate, reddish gray, very thick bedded, of rounded to angular clasts of andesite rocks, sandstone and mudstone rip-ups. Is intercalated with red to cream-colored, thick-bedded, medium- to fine-grained sandstone. Some beds include small pebbles. The red sandstone is lithic-rich, whereas the cream-colored one is quartz-rich. Few thin siltstone beds are intercalated. Fault contact with	7	607
40.	Shale (60%), red, thick bedded, is intercalated with red, medium-bedded, fine-grained sandstone (20%) and red, medium-bedded siltstone (20%). Unit is strongly fractured. Sharp contact with	9	616
41.	Shale, gray, thick bedded to massive, has few intercalations of thin-bedded sandstone and conglomerate of volcanic fragments. Exposure is very poor.	30	646
Covered	....	15	661
42.	Shale, green, thick bedded, foliated, is intercalated with red siltstone and red, fine-grained sandstone. Color changes to red toward the bottom. Unit is strongly fractured. Sharp regular contact with	11	672
43.	Conglomerate, purplish red to mottled, thick to very thick bedded, of rounded to angular andesitic clasts. It is intercalated with red, medium-bedded, medium- to coarse-grained and pebbly sandstone and medium-bedded with parallel lamination, medium-grained sandstone. Unit is capped by a 20 cm-thick sandstone bed with inverse graded bedding, from fine to medium and coarse, with some pebbles.	10	682
Covered	....	50	732
44.	Conglomerate, purplish gray, thick bedded, of well rounded to angular clasts in a sandy to silty matrix. There are intercalations of purplish gray, thick-bedded, medium- to coarse-grained and pebbly sandstone, and of medium-bedded siltstone. Strong fracturing observed in some places. Exposure is mostly covered, but scattered exposures suggest that the sequence continues. Transitional(?) contact with	72	804

Anita Formation, Lower member

	The upper part of the lower member is very poorly exposed. Scattered outcrops show the presence of andesitic conglomerates with a sandy matrix. Down section, the clasts become more angular and the matrix changes from sandy to volcaniclastic and volcanic. In the lower part, andesitic breccias with an andesitic matrix are more common.	76	76
1.	Breccia, dark gray, massively bedded. The clasts are angular to subrounded, poorly sorted, of andesitic composition. Their texture is porphyritic to aphanitic, with amphibole and plagioclase phenocrysts. Matrix varies from igneous to sandy. Few intercalations of purplish gray to red sandstone with a thin basal conglomerate. Fault contact with	12	88
2.	Sandstone, red, medium bedded, fine grained, has intercalations of red siltstone. Unit is fractured. Sharp irregular contact with	7	95
3.	Breccia, dark gray, massive, of angular and poorly sorted andesite clasts in a sandy matrix. Downward, the matrix changes to igneous, of the same composition as the clasts. Grades downward into an andesite flow. Covered contact with	9	104

Pozo Duro Formation

1.	Shale, red, thick to massively bedded, has intercalations of red to pink and purplish gray, massively-bedded, medium-grained sandstone, which are more abundant toward the top. The lower part of the unit is strongly fractured and poorly exposed. Sharp irregular contact with .	58	58
2.-	Sandstone, gray to green, medium bedded, fine grained. Toward the top there are white to green, silty calcareous concretions. Unit is strongly fractured. Fault(?) contact with	7	65
3.	Andesite sill, light green, porphyritic texture with amphibole phenocrysts. Sharp contact with	67	132
4.	Sandstone, red, medium bedded, medium to fine grained, is intercalated with red, medium bedded shale. Fine-grained sandstone is replaced by siltstone in the upper part of unit. At base of unit is a thin micritic limestone with septaria(?). Sharp contact with	7	139
5.	Shale and mudstone, red, thick bedded, with abundant fractures filled by caliche. Probable fault zone. Outcrop is very poor.	79	218
	Covered	7	225
6.	Mudstone, red, homogeneous, strongly fractured and faulted. The middle third of unit consists of an alternation of red, medium bedded, fine-grained sandstone and shale. Outcrop is poor.	31	256
	Covered	46	302
7.	Shale, dark purple to dark red, homogeneous, with calcareous nodules, locally very small and concentrated along bedding planes. Scarce intercalations of red, thick-bedded, fine-grained sandstone. Unit cut by a small strike-slip fault. Transitional contact with	41	343
8.	Sandstone, purplish gray, massively bedded with parallel, wavy and cross lamination, fine to medium grained. Sharp, irregular contact with	6	349
9.	Shale, light red, with very small calcareous nodules. Grades down into a red siltstone, which in turn grades down into a fine-grained sandstone. No bedding features observed. Few calcareous nodules in the siltstone. Fracturing is abundant. Sharp contact (fault?) with	9	358
10.	Shale, red, homogeneous, foliated, with very small calcareous nodules. Upper part displays an alternation of red to orange colors.	12	370
11.	Sandstone, green, medium bedded, fine to medium grained, is intercalated with green, medium-bedded siltstone. Unit is fractured and silicified. Sharp contact with	6	376
12.	Andesite sill, green, massive, microgranular to porphyritic texture with plagioclase and amphibole phenocrysts; very fractured.	40	416
	Covered	4	420
13.	Shale (80%), purplish red, medium bedded, is intercalated with purplish red, medium-bedded, fine-grained sandstone (20%). Calcareous nodules in the shale are small, abundant and forming lenses. Transitional contact with .	8	428
14.	Shale, green with patches of ocher red, thick bedded, is intercalated with medium- to thick-bedded, medium-grained sandstone. Transitional(?) contact with	6	434
15.	Siltstone, green to purple, thick bedded, with few intercalations of shale. The siltstone contains some calcareous nodules, mostly small, but some reach almost 30 cm in length. At the base is a gray, thick-bedded with parallel lamination, medium-grained sandstone. Sharp irregular contact with a red to green shale 2-m thick. It is foliated into pencil structure.	6	442
	Covered. Following units, 16 through 32 are poorly exposed. Description is based mainly on scree.	119	561
16.	Shale, red, homogenous and foliated.	20	581
17.	Sandstone, grayish purple, medium grained.	14	595
18.	Shale, same as in 16, but with scarce intercalations of gray, fine grained sandstone. Abundant calcareous nodules. Base of unit is formed by a 1-m-thick sandstone. ..	21	616
19.	Shale, red and foliated. Lower 3 m include thick intercalations of gray sandstone.	12	628
20.	Shale, red.	7	635
21.	Sandstone, gray, very thick bedded, medium grained. Lower 7 m display a bedding parallel cleavage.	11	646
22.	Sandstone, gray, with intercalated red shale. The upper 2 m of unit consist of a massive shale.	11	657
23.	Sandstone, gray, medium grained with a clayey matrix, is capped by a 2 m-thick shale.	7	664
24.	Sandstone, same as unit 23.	10	674
25.	Sandstone, gray.	4	678
26.	Shale, red, grades down into a gray sandstone	7	685
27.	Shale, red, grades down into a purple, homegeneous, medium grained sandstone with few intercalations of red, foliated shale. Sharp irregular contact with	5	694
28.	Sandstone, cream-colored, medium to thick bedded, medium to coarse grained and pebbly. Grades laterally into red mudstone. Sandstone is quartz-rich; pebbles are rounded to angular, poorly sorted and made of quartz-arenite. Sharp contact with	5	699
29.	Sandstone, dark gray, homogenous, structureless, medium grained. Sharp contact with	4	703
30.	Shale, dark red, homogeneous, with intercalations of cream-colored lenses of medium to coarse and pebbly sandstone. The sandstone is quartz-rich, and the pebbles are well rounded to angular and made of quartz-arenite. Exposure is poor.	13	716
	A sequence similar to unit 30 continues for about 56 m, but is barely exposed. Thickness is estimated with the position of the contact of the Pozo Duro Formation and the Cintura Formation below, as observed in a 1:20,000 aerial photograph.	56	772

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